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TRANSATLANTIC RESEARCH INTO AIR COMBAT ENGAGEMENTS (TRACE)

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FINAL REPORT

AIR VEHICLES DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542

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The foundation for the Transatlantic Research into Air Combat Engagements (TRACE) program was laid in 1992 with discussions held between Hannes Ross of Daimler Benz Aerospace (Dasa) and Don Gum of Air Force Research Laboratory (AFRL). At that time both Dasa and AFRL were interested in the development of combat pilot aiding systems. Both countries felt that there was significant value in conducting evaluations comparing the performance of the two country's pilot aiding systems: Integrated Control and Avionics for Air Superiority (ICAAS), developed by AFRL, and Automated Maneuvering Attack System (AMS), developed by Dasa. Since both of these systems were in development at that time, simulation was chosen as the best approach to conduct comparative research. Dasa had a simulation of AMS running at their facility near Munich, Germany, and Air Force Research Laboratory had an ICAAS simulation in Dayton, Ohio, USA.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Title **Page**

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Report Organization

The TRACE Final Report is splitted into parts as

- Part I: Program Description and Recommendations

and

- PART II: Description of the Technical Studies, Analysis and Results.

The Table of Contents summarizes this report as a whole and is completely included in both report parts as well as the Table of Figures and Tables.

Since this document was drawn up by both AFRL and Dasa in cooperation, the main author of the chapter and its subchapters can be identified by the label [] in the title.

Chapters written by one party were always inspected and its contents agreed by the other party to ensure a common understanding of the complete study report.

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Project Manager:	Capt Ron Johnston	Florian Graessel
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Transatlantic Research into Air Combat Engagements (TRACE)

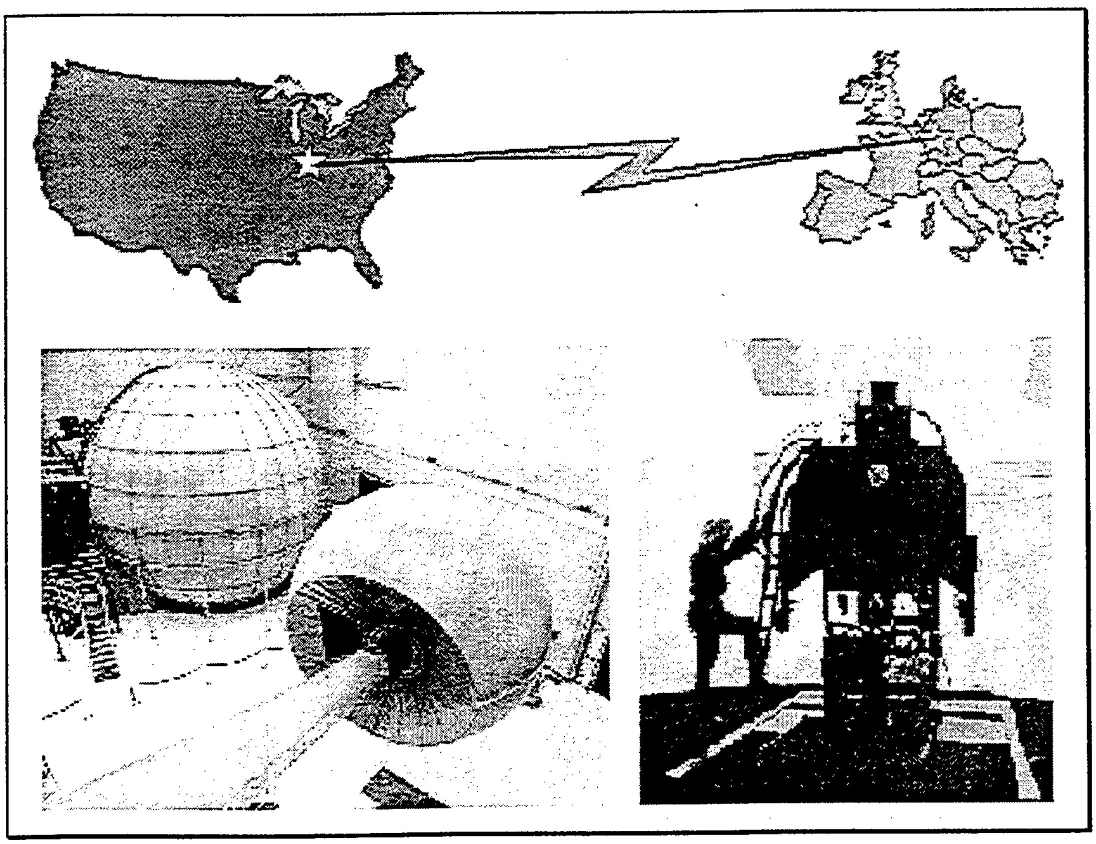
1 November 1995 - 31 March 1998

Final Report

Published 25 May 1998

Part I: Program Description and Recommendations

Chapters 1 to 4



1. Introduction [Dasa & AFRL]

1.1 Program Background

The foundation for the Transatlantic Research into Air Combat Engagements (TRACE) program was laid in 1992 with discussions held between Hannes Ross of Daimler Benz Aerospace (Dasa) and Don Gum of Air Force Research Laboratory (AFRL). At that time both Dasa and AFRL were interested in the development of combat pilot aiding systems. Both countries felt that there was significant value in conducting evaluations comparing the performance of the two country's pilot aiding systems: Integrated Control and Avionics for Air Superiority (ICAAS), developed by AFRL, and Automated Maneuvering Attack System (AMS), developed by Dasa. Since both of these systems were in development at that time, simulation was chosen as the best approach to conduct comparative research. Dasa had a simulation of AMS running at their facility near Munich, Germany, and Air Force Research Laboratory had an ICAAS simulation in Dayton, Ohio, USA. The original thought was to rehost one of these simulations at the other facility; however, there were many difficulties with that approach. Each simulation had been developed and hosted on different computer systems. This made rehosting the simulations difficult. A significant amount of manpower and equipment investment would have been required to get both simulations operating in the same facility. There were also significant security issues to resolve to implement the approach due to the classification, and proprietary nature of the software code which implemented the combat pilot aiding algorithms.

Although in its infancy, simulator networking was of interest to both countries. Researchers in both Germany and the US believed that network simulation had the long-term potential to provide a powerful means to conduct cooperative research and evaluations. Dasa and AFRL had conducted network simulations within their own country and realized that there were some significant performance issues which needed to be resolved before the network quality was good enough to conduct comparative evaluations between AMS and ICAAS. These issues were evaluated and it was jointly decided that if the network issues could be satisfactorily resolved, that simulation networking would be the best and lowest cost approach for conducting the AMS and ICAAS evaluation. If successful, this evaluation would also lay the foundation for future cooperative research between the two countries.

Between 1992 and 1995, there were ongoing discussions between the Dasa and AFRL, and the concept of the Transatlantic Research into Air Combat Engagements (TRACE) evolved. An approach was developed which split the TRACE program into two distinct phases. Phase I was to develop, optimize, test and evaluate a joint network simulation. Phase II was to use the network to conduct the comparative evaluation between AMS and ICAAS.

Establishing the Memorandum of Understanding (MOU) to conduct the TRACE program, and funding the program proved very difficult for both the US and Germany. Requirements for establishing the program agreements changed through the 1992 to 1995 period. Various funding sources were identified and subsequently disappeared. In 1995, an "umbrella" MOU between Germany and the US to conduct joint research was established. The TRACE program was defined and Phase I of TRACE became ANNEX 3 to the umbrella MOU in November 1995.

In retrospect, dividing the program into two phases was not a good idea. It was done to minimize risk, and to simplify approval since Phase I was totally unclassified and did not require special security approval. Unfortunately, by starting the program with approval for only Phase I, the overall objective to conduct comparative research between combat pilot aiding systems was not perceived by senior management; that portion of the program was to have been accomplished in Phase II. This was later to become a significant issue for funding and program continuation as described in section 2.1.2.

Phase I of the TRACE program was kicked off in November 1995 with a joint meeting between Dasa and AFRL at Wright-Patterson Air Force Base, Ohio. Many of the program details were worked out at that meeting. The meeting established an excellent working relationship between the engineers and managers at Dasa and AFRL which lasted throughout the program. For example, the idea for weekly Wednesday telephone conversations was established. The weekly conversations served to coordinate the work between the two facilities throughout the program.

The following indicates a brief summary of when each task was completed:

Date	Event
Nov 95	MOA signed
Nov 95	TRACE kick-off meeting
Jul 96	Initial US-German network connections
Aug 96	Start network/protocol testing
Oct 96	First US-German simulation connections
Sep 97	First US-German full simulation scenarios
Oct 97	Start piloted tests
Mar 98	Phase I completion

1.2 Program Objectives

The TRACE Phase I program objective was to

1) perform United States Air Force (USAF) and German Ministry of Defense (MOD) research in the area of long haul simulator network technology by coupling the simulation facilities of Air Force Research Laboratory (AFRL) and Deutsche Aerospace (Dasa),
2) conduct simulations showing the technical capabilities/limitations for potential operational use for aircrew training, and
3) establish the necessary conditions required for a comparison of the combat pilot aiding systems developed by both parties.

Specific objectives included establishing, optimizing, testing, and evaluation a robust high-fidelity simulation network between Dasa and AFRL. Two different networks were evaluated. One was a 128Kb/s commercial ISDN telephone network, and the second was a 128 Kb/s Defense Simulation Internet (DSI) connection. Three different protocols were evaluated on each of the networks;

1) the Distributed Interactive Simulation (DIS),
2) the German distributed network protocol referred to as "Dasa protocol", and
3) DIS-Lite which was an efficient version of DIS.

One objective was to implement each of the protocols on both networks and to measure the performance using the Simulator Network Analysis Project (SNAP) hardware. A significant objective was to implement a high-fidelity joint simulation on the optimized network which included multiple piloted highly dynamic fighter aircraft with missiles, guns, radar, etc., and multiple digital players.

The final TRACE Phase I objective was to demonstrate the ability of an optimized international simulation network to support joint training and research.

The program objectives are

- Design and Implement a Transatlantic Network Simulation Architecture to Support Highly Dynamic Vehicles
- Evaluate Alternate Links and Various Network Protocols
- Thoroughly Test and Characterize Network Performance
- Show Technical Capabilities/Limitations for Operational Use

2. TRACE Program Background [DASA & AFRL]

2.1 TRACE Annex

2.1.1 Verification of Completion of Each Task

In the following, the verification of all the main tasks in the TRACE-program are described. Both AFRL and DASA were working on all tasks in cooperation. For correct and efficient completion of these tasks, the technical support of each party was indispensable (i.e. if installing SNAP or DASA-Protocol).

2.1.1.1 Task 1: Program Preparation

This Task was completed in December 1995.

2.1.1.2 Task 2: Network Development & Prototyping

The network was specified and a detailed schedule for the development was drawn up. After procuring the required hardware a critical design review was performed, the link between DASA and AFRL was established and tested via both an ISDN and a DSI line.

The DASA-, DIS- and additionally DIS-Lite protocols were implemented on the simulation systems. For the DASA implementation a standalone NIC was shipped to and installed at AFRL and the interface adapted to that of the AFRL-simulation. At DASA a DIS and a DIS-Lite interface were developed and tested.
The DIS-Protocol was adapted to cover TRACE requirements and used as the German/American air force related simulation protocol.

Later, the SNAP equipment was shipped, installed at DASA and initial measurements were performed.

A voice communication link was established first with a special DIS-Radio and later, because of performance problems, via standard analog telephone line.

Data recording systems were developed and used for theoretical performance tests using the DIS- and DASA-Protocol

2.1.1.3 Task 3: Assessment Simulation Preparation

The AMS simulation was reactivated and detailed plans were developed. The simulation models were generated and exchanged between the Dasa and AFRL if necessary. Existing aircraft and avionics models were improved and parts of the weapons model, the G-dimming and G-loc models were exchanged.

The simulations were networked both via DSI and ISDN links and fundamental tests were performed with the first versions of the network interfaces. Measurements with the SNAP equipment and basic functionality tests of the three protocols, the models and the simulations were performed in this phase.

2.1.1.4 Task 4: Simulation Checkout

Both the AFRL and the DASA simulations were checked out as well as the established network. For performance reasons and the unreliability of the DSI, ISDN was chosen for the networking media.

Flight tests were performed using the test scenarios developed for the productions runs with all three protocols. Technical problems that occurred during the tests were corrected.

2.1.1.5 Task 5: Assessment Simulation Production Runs

For the productions runs 5 scenarios with increasing complexity has been developed to ensure the pilots familiarization as well as the possibility for tactical training in complex combat engagements. For a mission with a common German-American force against a force of computer generated forces, the requirements of the TRACE program were exceeded. This new requirement called for the DASA simulation to control 6 independent aircraft (with all their missiles).

During the production runs, two scenarios with even greater complexity were requested by the pilots. These scenarios were generated to intensify the effect of training during the joint missions.

After each run and at the end of each day, pilot debriefings were held with between all pilots involved in the testing and the system engineers. These debriefings resulted in some modifications to the simulations to provide the best test and training effect.
As one result some modifications has been done on the simulations to ensure the highest possible test and training effect. The debriefing was supported by a local quick look functionality after each session.

At the end of this phase, two separate demonstrations were performed with both DASA and AFRL participating followed by a final debriefing. Finally, the pilots composed a pilots report.

2.1.1.6 Task 6: Analysis and Recommendations

The collected data was analyzed with the results and protocol recommendations shown in this final report (see Chapter 4).

2.1.2 AFRL Funding

The TRACE program was jointly funded by Germany and the US. Each country agreed to fund research in its own respective simulation facility. The signed TRACE Annex to the MOU between Germany and the US agreed to the following funding profile:

TRACE Phase I FUNDING (in $ M)

	PREV	FY96	FY97	FY98	TOTAL
US Air Force	0	.748	.843	.950	2.541
German MOD	0	.993	1.920	.860	3.774

The US funding of the program ~~proceeded on this profile up until FY98.~~ The US portion of the TRACE program was reviewed by a high level representative of DDR&E, Dr. Dix, during his March 1997 TARA review at Wright Laboratory. Despite excellent Phase 1 results, Dr. Dix was very critical of the TRACE program because he feels that flight control funds should not be spent on network technology even if it supports future flight control research. Based on his negative comments, there was a serious funding cut to TRACE Phase I in FY98. The Flight Control Division of Wright Laboratory only funded $45K to the TRACE program in FY98. The remainder of the funding for personnel, equipment, line rental, and facilities was made up through other sources. In total, approximately $550K in funding from all sources will be expended by the US during FY98. Total US funding for the entire program will be approximately $2.1M.

2.1.3 TRACE Goals

By networking simulation facilities on opposite sides of the Atlantic ocean, the TRACE Program will develop and demonstrate the technology necessary to conduct integrated research and training simulations involving diverse NATO aircraft across long distances. Phase I will define and implement a network architecture using different networks and protocols, such as the Distributed Interactive Simulation (DIS) and the DASA's protocols on the Defense Simulation Internet (DSI) or on a standard ISDN telephone line. The Simulation Network Analysis Project (SNAP) computers will measure the network performance achieved.

Program Objectives:

- Perform USAF and MOD research into long haul simulator network technology by coupling the simulation facilities of AFRL and DASA.
- To conduct simulations showing the technical capabilities/limitations for potential operational use in aircrew training.
- Determine feasibility for developing a common American/German protocol optimized for Air Force applications.

2.2 TRACE SOW

The TRACE Statement of Work (SOW) established the program organization, technical requirements and division of responsibilities for the program.

The SOW TRACE jointly organized the program between the German Ministry of Defense and the United States Air Force. Responsibility for accomplishment of the program was assigned to Air Force Research Laboratory's Control Integration and Assessment Branch located at Wright-Patterson Air Force Base, Dayton, Ohio and Deutsche Aerospace (DASA) located in Munich, Germany. The SOW enumerated the technical requirements for the project through the following Work Breakdown Structure:

TRACE Phase I Work Breakdown Structure

1.0 Program preparation
- 1.1 Coordination meeting at WPAFB
- 1.2 Program planning
- 1.3 Resolve detailed networking issues
- 1.4 Joint program discussions
- 1.5 MOU annex preparation
- 1.6 MOU signed
- 1.7 DEA DDL preparation
- 1.8 DEA DDL signed

2.0 Network development & prototyping
- 2.1 Establish & test network
- 2.1.1 Define network specification
- 2.1.2 Develop detailed networking plans
- 2.1.3 Procure hardware
- 2.1.4 Establishment of network link between facilities
- 2.1.5 Test link using newest available DIS protocol
- 2.1.6 Test link using DASA's simulation protocol
- 2.1.7 Develop a common German/American air force related simulation protocol
- 2.1.8 SNAP network performance measurement
- 2.2 Establish voice communication link
- 2.3 Establish capability for data recording
- 2.4 Link established

3.0 AMS/ICAAS simulation preparation
- 3.1 Reactivate AMS Simulation
- 3.2 Develop detailed AMS/ICAAS simulation plans
- 3.3 Generate standardized simulation models
- 3.3.1 Generic aircraft model
- 3.3.2 Generic weapon model
- 3.3.3 Generic avionics models
- 3.3.4 G-Dimming and GLOC models
- 3.7 Fundamental network test

4.0 Simulation checkout
- 4.1 Definition & realization of baseline functions
- 4.2 WPAFB simulation checkout
- 4.2.1 Verify generic USAF Fighter
- 4.3 DASA simulation checkout
- 4.3.1 Verify baseline GAF
- 4.4 Network integration checkout
- 4.5 Test flights
- 4.6 Analysis & corrective actions
- 4.7 Ready for production runs

5.0 Evaluation production runs
- 5.1 Pilot training
- 5.2 Data collection
- 5.2.1 Scenario1 1 + 1
- 5.2.2 Scenario2 1 vs 1
- 5.2.3 Scenario3 2 vs 2
- 5.2.4 Scenario4 2+2 vs 2+2
- 5.2.5 Scenario5 4 vs 2+2
- 5.3 Pilot debriefing
- 5.4 Data quick look
- 5.5 Preliminary report
- 5.6 Demonstration
- 5.7 Simulator and network support

6.0 Analysis & recommendations
- 6.1 Data analysis
- 6.2 Protocol recommendations
- 6.3 Final report
- 6.4 Briefing to customer

The SOW provided a detailed task description and defined each organizations responsibilities to accomplish the tasks and sub-tasks. It also included a 2 year, 3 month schedule to complete TRACE Phase I. The SOW outlined the entire TRACE project into four phases.

2.3 TRACE Schedule

Kickoff Meeting	Nov 95
Network Link Established	Aug 96
Start SNAP Latency Tests	Oct 96
Common Protocol Developed	Feb 97
Network Test Complete	Apr 97
Simulations Linked Across Network	Sep 97
Simulation Checkout Complete	Sep 97
Assessment Simulation Runs Complete	Nov 97
Analysis and Recommendations	Mar 98

2.4 TRACE Personnel

2.4.1 AFRL/VACD Personnel

Name	Main Duty	Additional Duties
Lt. Stephen Purdy	TRACE Program Manager (AFRL/FIGD Side)	• SNAP Operator • VTC Hardware
Ron Ewart	AFRL/FIGD Chief Scientist	• TRACE Program Advisor • Communications Hardware • Simulator Hardware
Dan Caudill	Simulation & Executive Programmer	• AFRL/FIGD Pilot Coordination
Roger Wuerfel *Halifax Contractor*	Networking Programmer	• Expert on DIS, DIS-Lite Protocols • AFRL/FIGD SCRAMNet Code • NIC Integration into AFRL/FIGD Simulation • VR-Link Integration at AFRL/FIGD & DASA
Capt. Ron Johnston	Network Setup (ISDN/DSI/SCRAMNet)	• SNAP Operator • Communications Hardware
Lt. David Barnhart	SNAP Program Lead	• Expert on DIS, DIS-Lite Protocols
Kevin Maloney *Halifax Contractor*	Simulation Programmer	• DASA Missile Model Integration at AFRL/FIGD
Ernie Payne *Halifax Contractor*	AFRL/FIGD RADAR Lead	• DASA RADAR Model Integration at AFRL/FIGD
Lt. Rob Subr	Simulation Graphics	• VBMS Programmer/Operator
Larry Mutschler	AFRL/FIGD Database Lead	
Don Gum	AFRL/FIGD Branch Chief (retired January 1997)	• Initiated TRACE Program
Ed Allen	SNAP Operator	

2.4.2 DASA Personnel

Name	Main Duty	Additional Duties
Dr. Klaus Holla	Program Manager	
Florian Gräßel (Graessel)	Technical Leader/Manager	• Testpilot • Data Recorder • Data Analysis
Herbert Eibl	Simulation Software	
Johann Neuhauser	DASA & DIS Protocol	
Diedrich Hartung	Simulation Software	• Testpilot
Wolfgang Bader *DASA contractor*	DASA NIC	
Karl Scalet *DASA contractor*	Networking (ISDN/DSI)	• DASA NIC • DASA & DIS Protocols
Arthur Lutzenberger	Data Recorder	
Robert Hoogvliet	DASA SNAP Operator	
Wolfgang Ponikwar	DIS Radio	
Franz Sulzberger	Simulator Hardware (cockpit)	• Testpilot

2.4.3 Other TRACE-Related Personnel

Name	Main Duty
Johann Pogarell	German MoD
Jobst Frank	German Liaison at Wright-Patterson Air Force Base
Jerri Messinger	International Programs Manager at Wright-Patterson Air Force Base
Don Gum	AFRL/VACD Branch Chief that headed US efforts for TRACE (now retired)

2.5 AFRL/VACD Simulation Facility [AFRL]

2.5.1 Background/Introduction

The AFRL/VACD simulation facility began initial operation in 1979. The majority of the research performed at this facility since its inception has been flying qualities and flight control related. In 1989, the Integrated Control and Avionics for Air Superiority (ICAAS) program requested simulation support from within the Flight Control Division and the first in-house, multi-ship, air combat simulation was born. The ICAAS program essentially paid for the purchase and development of the Mission Simulator One, the Piloted Combat Stations, the mission planning rooms, the main simulation control room, and most of the simulation and graphics computers. These components of the facility are the main assets that have been utilized by the TRACE program. A description of the majority of the assets in the AFRL/VACD facility are described in the following sections.

2.5.2 AFRL/VACD Simulators

The AFRL/VACD simulation facility contains three main simulator types: Mission Simulator One (MS-1), the Large Amplitude Multi-Mode Aerospace Research Simulator (LAMARS), and the Piloted Combat Stations. These simulators and the AFRL/VACD simulation computers are normally controlled from one of two simulation control consoles. These simulators, as well as the control consoles and simulation computers, will be described in the following sections.

2.5.2.1 Mission Simulator-One (MS1)

The Mission Simulator One is a forty foot diameter dome simulator capable of up to 360° visual field of view with or without a 40° high resolution area of interest inset directly in front of the pilot. The cockpit configuration can be modified to satisfy individual simulation requirements and the entire cockpit can be replaced with a new cockpit design if needed. The main capability provided by the MS-1 is Air-to-Air combat mission simulations, although it can be used effectively for other types of simulations as well. The resolution and contrast of the visual scene provided to the pilot make the MS-1 least suited for Air-to-Ground missions where visual identification of the target is necessary. A picture of the outside of the MS-1 can be seen in Fig. 2-1.

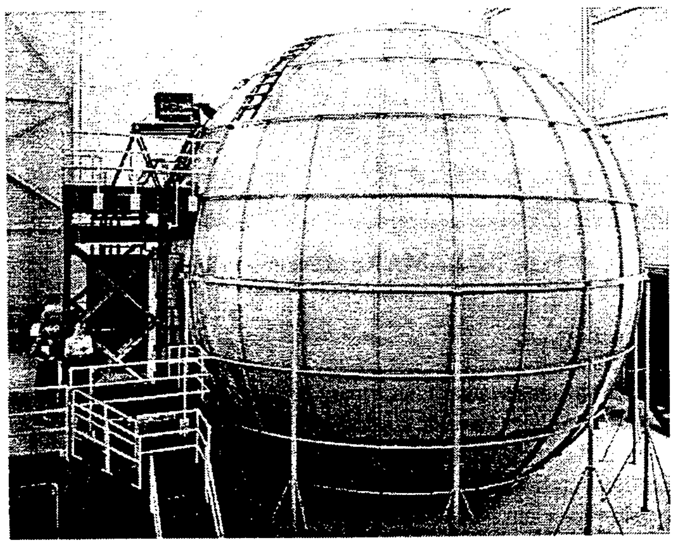


Fig. 2-1 Mission Simulator One (MS-1)

2.5.2.2 Large Amplitude Multi-Mode Aerospace Research Simulation (LAMARS)

The LAMARS is a unique simulator that combines a twenty foot diameter dome cockpit on a 30 foot arm with a 5 DOF motion system. The range of displacement available at the cockpit is +/-10.0 feet vertically and laterally as well as an angular capability of +/-25.0° in each of the roll, pitch, and yaw axes. The LAMARS simulator has the capability to generate instantaneous load factors at the pilot station of +/- 3.0 Gs vertically and +/- 1.6 Gs laterally. It can also provide instantaneous angular accelerations of +/-400.0, +/-460.0, and +/-200.0 degrees/second^2 in the pitch, roll, and yaw axes, respectively. These features combined give the LAMARS outstanding force cueing capability for piloted simulations. The cockpit is similar in flexibility to the MS-1, but the LAMARS visual system is limited to a 180° field of view that is projected on the inner surface of the dome. The LAMARS is typically utilized in flying qualities and flight control research simulations, but can be utilized effectively in mission simulations as well. A picture of the LAMARS with the MS-1 in the background can be seen in Fig. 2-2.

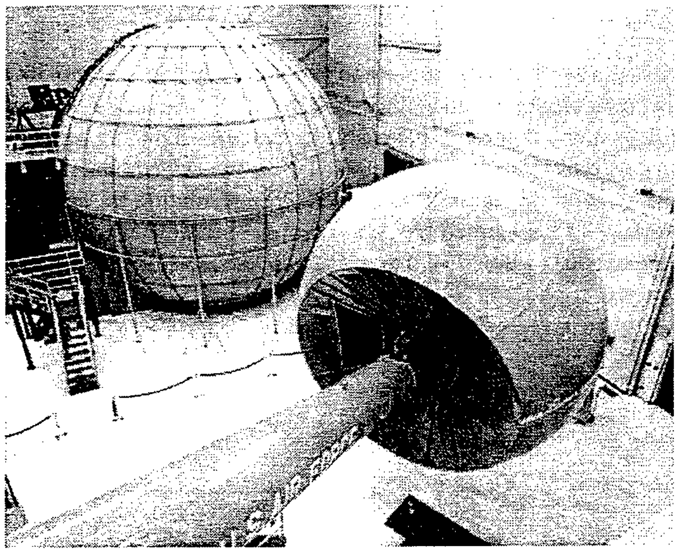


Fig. 2-2 LAMARS (foreground) and MS-1

2.5.2.3 Piloted Combat Stations

The Piloted Combat Stations are simulators that encompass basic cockpit functionality with limited out the window field of view. They are a lower cost alternative to adding additional manned players into multi-ship air combat simulations and can also be used for other simulations not requiring a high fidelity cockpit and visual system. The basic components of these combat stations are a stick, a throttle and a high resolution, 29" monitor for all visual displays. Stick and throttle grip types can be reconfigured as needed and various display formats can be utilized to satisfy a given simulation's requirements. Currently, AFRL/VACD has six of these types of combat stations, one of which is enhanced with projected out-the-window (OTW) visuals. A picture of one of these types of stations can be seen in Fig. 2-3.

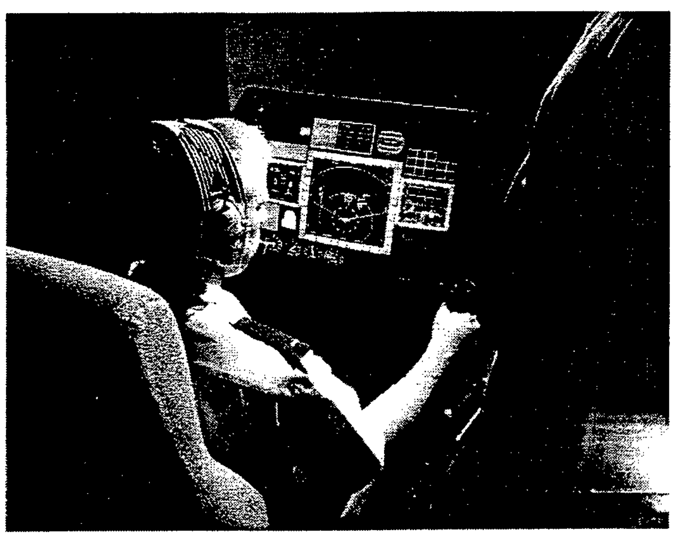


Fig. 2-3 Piloted Combat Station

2.5.3 Simulation Control Consoles

AFRL/VACD controls most in-house simulations from one of two simulation control consoles. The first console is called the Flying Qualities Console (FQC) and is mainly used for flying qualities and flight control research

simulations. The FQC is a relatively small console that contains several video monitors, one VCR, a flight stick, and a variety of lights, buttons, sliders and knobs that can be used to control or test a simulation.

The other console is officially called the Simulation Control Console (SCC), but is more commonly known as the MOAC (Mother Of All Consoles). This console is typically used for the multi-ship combat simulations where a large number of monitors are required to view all aspects of the simulation. This console contains numerous video monitors, three VCRs, a flight stick, and a variety of lights, buttons, sliders, and knobs that can be used to control or test a simulation.

Both consoles and all simulator stations have their video sources controlled by a facility video switch. All video is controlled by this switch and it allows the simulation engineer the ability to switch any video source to any compatible video destination. This includes video for console monitors, VCRs, cockpit displays, HUDs, projectors, etc. There is also the capability for complete video setups to be saved to a file called a salvo. Salvos allow video configurations to be reloaded quickly and easily without the simulation operators having to individually program each video source to each video destination.

2.5.4 AFRL/VACD Simulation Computers

The main simulation computers utilized in the AFRL/VACD simulation facility are manufactured by Encore Computing. The facility uses three single processor RSX computers and two four processor Model 91 computers for the majority of the simulation model processing. The RSX computers have Encore's MPX real-time operating system and the 91s utilize a UNIX based operating system. These computers are all connected together via a reflective memory bus for communication, and they utilize hardware interrupts between the computers for processor activation and control. The reflective memory bus has been partitioned to allow each simulation to have its own piece of reflective memory for implementing their particular definition of Datapool. Datapool allows all of the simulation processes access to most or all of the simulation data, i.e. aircraft states, weapon states, sensor states, simulator states, etc. Each simulation engineer can tailor their definition of Datapool to meet the requirements of their particular simulation. These computers also communicate with other simulation support computers through Ethernet and SCRAMNet rings.

2.5.5 AFRL/VACD Simulation Support Computers

The simulation support computers at the AFRL/VACD facility consist of a variety of Silicon Graphics computers, a CAMAC hardware I/O system, an Ensoniq sound system, and several other minor components that may be needed by a given simulation. The Silicon Graphics computers are used to generate and display HUD symbology, the head down displays, God's eye displays, high resolution targets, and any other graphics that may be required by the simulations. The CAMAC hardware I/O system allows the simulation computers to communicate with all of the cockpit hardware, i.e. sticks, throttles, etc. The hardware is configured such that individual simulator stations can be added or removed from a particular simulation's hardware loop through the use of a programmable fiber optic highway driver. The sound system is also tied into this loop and is driven by the simulation through the CAMAC system.

2.5.6 AFRL/VACD ESIG

The AFRL/VACD facility utilizes two Evans & Sutherland 4530 image generators for the majority of its out the window scene generation. The first system is capable of generating one high resolution or two low resolution video channels while the second system is capable of generating two high resolution or six low resolution video channels. These image generators can be setup to run at 30 Hz or 60 Hz rates and can also be configured to run synchronously with the simulation computers. When running synchronously, the image generators are actually controlling the simulation timing instead of the master computer. Communication between the image generators and simulation computers can be performed through SCRAMNet or Ethernet, but synchronous operation can only be accomplished via SCRAMNet. These image generators have access to several different databases at the AFRL/VACD facility. Databases of Lake Mead, Whidbey Island, Nellis AFB, and Tyndall AFB are available for use by in-house simulations. Each database has its own set of terrain features, moving models, and animation sequences that can be activated and controlled by the simulation as needed.

2.6 DASA Simulation Facility [DASA]

2.6.1 Background/Introduction

For years, department MT64 (Simulation) of Daimler-Benz Aerospace has been working on the interconnection of flight simulators for training purposes in support of national and European projects. The development for these projects are generally based on ISDN-links, concentrating on decreasing the network load and raising the accuracy of the virtual entities.

The main focus is to support pilot training in tactical situations that are difficult or dangerous in real life situations and for preparing for real life training.

2.6.2 DASA Simulators

2.6.2.1 Integration Cockpit

The Integration Cockpit is a small, simple generic cockpit. It is generally used for development and integration. Nevertheless, it has most of the features of the other cockpits and encompasses basic cockpit functionality. It is equipped with a side stick, a simple throttle and a high resolution monitor for all main head down displays. If needed it is possible to add a low cost backprojection visual system for a limited out-the-window visual.

2.6.2.2 VLO Cockpit - Simulator

The VLO-Cockpit is a transportable cockpit which combines the simulation computer for avionics and weapon systems with the network interface computer and the sound system in a single unit. The system is an extremely modular design and easy to install for exhibitions and demonstrations.

The VLO-Cockpit is a full equipped generic cockpit with complex stick and throttle, three standalone high resolution monitors for head-down-displays (HDD) and a head-up-display (HUD). For an out-the-window view, backprojection equipment can be placed in front of the cockpit.

Additionally, this unit can generate multiple hostile and friendly CGT's to allow the cockpit to act as a standalone training simulator

2.6.2.3 Dome Simulator

The operators view of the outside world is created by 6 channel CGI which can display 4000 total faces. A range of databases from the desert to New York can be loaded and filled quickly with a host of moving models and special effects.
The images can be displayed in a 9meter 6-channel dome or on individual graphic monitors. Additionally, the dome allows for quick replacement of different cockpit types or "crew stations". An exchange of a 1.5 ton cockpit can be performed in only 20 minutes.

2.6.2.4 CGT - Computer Generated Targets

For the most complex scenarios multiple Computer Generated Targets were involved into. These CGT's ware all running on one SPARC-2CE CPU-card within the VLO-Cockpit-Simulator as shown in the table above. Up to six CGT's were used at least in a scenario especially created on demand of the pilots to enable a training situation with up to twelve flying entities. All these six CGT's were running on the same CPU within a 20Hz frame rate.

2.6.2.5 SAM - Surface to Air Missile Module

This module models the radar site of surface to air missiles on the fire platoon level and represents the Hawk and patriot missiles.

This Surface-to-Air-Missile Module provides a real-time simulation of ground based threats for ComAO scenarios. It includes modeling of radar sites and missile flyout. Effects of IFF and jamming are included. Combat behavior on the Fire Platoon level is provided. On a typical graphical user interface, the actual status and reaction of defined firing positions are displayed. Generic models for HAWK and PATRIOT are available. The module is network capable.

2.6.3 Simulation Control Center

2.6.3.1 Dome Simulator

The simulation is controlled and monitored from a control room equipped with 20 color monitors to keep the operator informed of every detail.

Additionally, there is a nearby briefing room with room for up to 20 people and 2 large screen to view and/or review the simulation runs.

2.6.3.2 Scenario Manager

This module is used to setup the tactical training and/or for visualization and debriefing.

For setup, you can configure all playing entities by determining the type and role, the force identification, flares, fuel and the armament. All entities can be placed at an initial position and given them, particularly the CGT's, a flight route (bulls eye for example).

While training, the Scenario Managers enable the user to watch the scenario by displaying a "God Eyes View" or a magnified view with additional information such as speed and altitude.

Another very important function is the ability to record all data for the debriefing of the networked scenario. This recorded data can then be replayed even if a different networked training session is performed in parallel.

2.6.3.3 Fighter Control Station

This module enables a fighter controller to participate within the training.

This module is a generalized replica of a typical fighter controller station allowing controllers to be included in virtual ComAO scenarios. It provides a user interface with realistic symbols and required functionality. It is combined with a voice link and is network capable.

2.6.4 DASA Simulation Computers

2.6.4.1 VLO- and Integration Cockpit

A FORCE VME system using Sparc technology is used for simulation of the avionics and weapon model. This system enables the user to add CPU-cards for increased system power and performance. The VME-bus system allows parallel computing of avionics simulation, weapon system simulation, Computer Generated Targets, network interfacing and the complete synchronization by exchanging data via a standardized shared memory architecture for all involved simulation systems. This simulation platform is completely integrated within the VLO-Cockpit-Simulator.

2.6.4.2 Dome Simulator

- Simulation Computer
  The simulation computer has 8 parallel Power PC 604 Risc (200Mhz) processors with approximately 800 Mips total performance, 128 MB local- and 32MB global memory. The input/output is handled by a dual high performance VME-system. It is controlled by a UNIX realtime operating system. Data is exchanged between host computer and cockpits via fiber-optics ScramNet interfaces.
- G-system
  The G-forces encountered by the crew of high performance aircraft can be simulated by a G-cueing system consisting of a G-seat and a G-suit driver.
- Sound System
  Digital recordings of the original sounds can be mixed together under computer control and played back synchronous with the simulation.

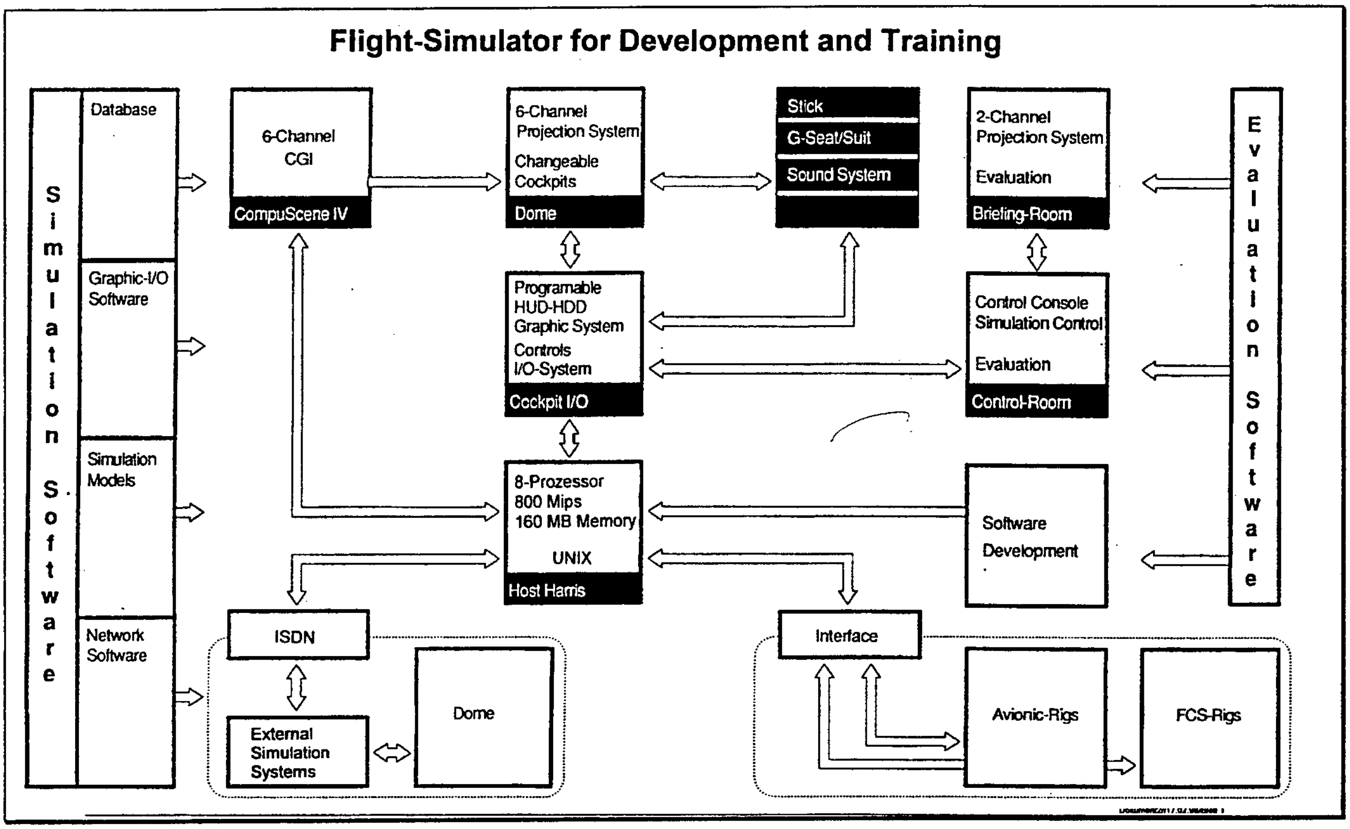


Fig. 2-4Blockdiagram of the Dasa Dome Simulation

2.6.4.3 Additional Modules

The networking modules as the Scenario Manager, SAM-Site-Module and the Fighter Control Station run on Silicon Graphics computers.

2.6.5 DASA Database Generators

The VLO Cockpit-Simulator and the Integration Cockpit can use three different quality image generators:

- an ESIG 2000, normally used with the VLO-Cockpit
- a SGI Onyx with Reality Engine^2, a good alternative to one of the other IG's
- a SGI O_2 as a simple IG for integration phases, normally used with the Integration Cockpit
- a Compuscene IV, used as an IG for the Dome Simulator.

The first three IG's are completely interchangeable and normally connected to a handy backprojection visual system. For all four IG's there is same correlated database, Lake Mead area, available, allowing all the simulators to be connected together. The CGT's use a digital map of this area.

3. TRACE Simulation [DASA & AFRL]

3.1 AFRL/VACD Simulation [AFRL]

3.1.1 Simulation Hardware

3.1.1.1 Computer Systems

3.1.1.1.1 Simulation Processors

The TRACE simulation utilized two Encore RSX computers and two Encore 91 Series computers for the simulation executive and model processing. A maximum of seven separate processors were activated on these four computers for the TRACE simulation tests. The simulation executive was configured to run synchronized with the image generation systems at a 30 Hz frame rate. Most software processes were run at the 30 Hz rate while some of the display drivers were run at 15 Hz. The following table details what simulation software was running, the rate it was scheduled to run, and the processor where each component was located.

Computer System	Processor #	Software/Process	Rate
Encore RSX (J)	1	Sim Executive	30Hz
		Hardware I/O	30Hz
		Network I/O	30Hz
		IG Drivers	30Hz
		Target Projectors	30Hz
		Missile Warning Sensor	30Hz
		HDD Drivers	15Hz
		VBMS Driver	15Hz
Encore RSX (G)	1	F-15 Model (indexed)	30Hz
		HUD Drivers	30Hz
		20mm Gun / Reticle	30Hz
		Fire Control	30Hz
Encore 91 (H)	1	Aircraft #1 Missiles	30Hz
	2	Aircraft #2 Missiles	30Hz
	3	Aircraft #3 Missiles	30Hz
Encore 91 (I)	1	Radar Model (indexed)	30Hz
	2	Aircraft #4 Missiles	30Hz

3.1.1.1.2 Graphics Computers

The TRACE simulation incorporated eight Silicon Graphics computers for graphic displays processing. These computers handled the cockpit displays, HUDs, high resolution target image, and the Virtual Battlefield Management System (VBMS). These graphic systems are driven through an Ethernet network that operates asynchronous from the rest of the simulation. Displays are updated by the simulation display drivers, at the rate at which they are scheduled, and the graphics update as soon as they receive those data packets. The following table details where all of the individual display software was located.

Computer System	Model	Graphics Application
Silicon Graphics #2	4D/85GT	F-15 HUD
Silicon Graphics #3	4D/85GT	High Resolution Target
Silicon Graphics #6	4D/310VGX	HDD/EFOV
Silicon Graphics #8	4D/70GT	HDD/EFOV
Silicon Graphics #9	4D/85GT	HDD/EFOV
Silicon Graphics #10	4D/85GT	HDD/EFOV
Silicon Graphics #15	ONYX RE2	F-15 HUD/EFOV
Silicon Graphics #20	INDIGO2	VBMS

3.1.1.1.3 Image Generator

The TRACE simulation used two Evans & Sutherland model 4530 image generators for controlling the OTW visual scene in the MS-1 and Super MCS. The Lake Mead database, converted by DASA, was utilized to ensure that both ends of the network simulation were flying over the same terrain. As mentioned earlier, the TRACE simulation was configured to run synchronously with these image generators at a 30 Hz frame rate.

3.1.1.2 Simulator Stations

The TRACE simulation utilized up to four different cockpits at the AFRL/VACD Flight Simulation Facility. The first is a 40 ft diameter dome called the Mission Simulator 1 (MS-1). The second cockpit is a manned combat station called the Super MCS, while the remaining two stations are generic manned combat stations. All stations are connected to a common intercom system that can be configured to allow communication between any combination of stations that is desired. In the TRACE simulation, all stations could communicate with each other.

3.1.1.2.1 Mission Simulator 1

The MS-1 cockpit is placed on a platform so the pilot's head is located approximately in the center of the dome while flying. A visual scene is projected on the inner surface of the dome by two General Electric light valve projectors with the video generated by two channels from an Evans & Sutherland 4530 computer image generator. The first channel provides video for all of the front hemisphere except for the 40° area of interest (AOI) cutout. The second channel has a 40° diameter field-of-view which is inset into the AOI cutout and provides high resolution imagery directly in front of the pilot. The visual scene moves in reaction to pilot flight control inputs and provides visual flight capability. The visual cues give a sensation of motion; however, the cockpit does not move at any time.

Two types of target projectors are used to display other vehicles. One high resolution color target projector pair provides a high quality depiction for one vehicle. Four laser target projector pairs provide wire-frame drawings for up to 4 more vehicles. The high resolution projector and laser projectors display the aircraft on the dome surface in all quadrants and provide sufficient cues of target range, aspect angle, and flight path for visual air-to-air engagements.

A high resolution 29" monitor is used in the cockpit to present the simulated advanced head down display, Cockpit 2000. There is no actual HUD hardware in the MS-1 cockpit, so the HUD is simulated by projecting it onto the dome at the appropriate location in front of the pilot. However, actual F-15 center stick and dual throttle grips were integrated into the simulator. Some pictures of the inside of the MS-1 can be seen in Fig. 3-1.

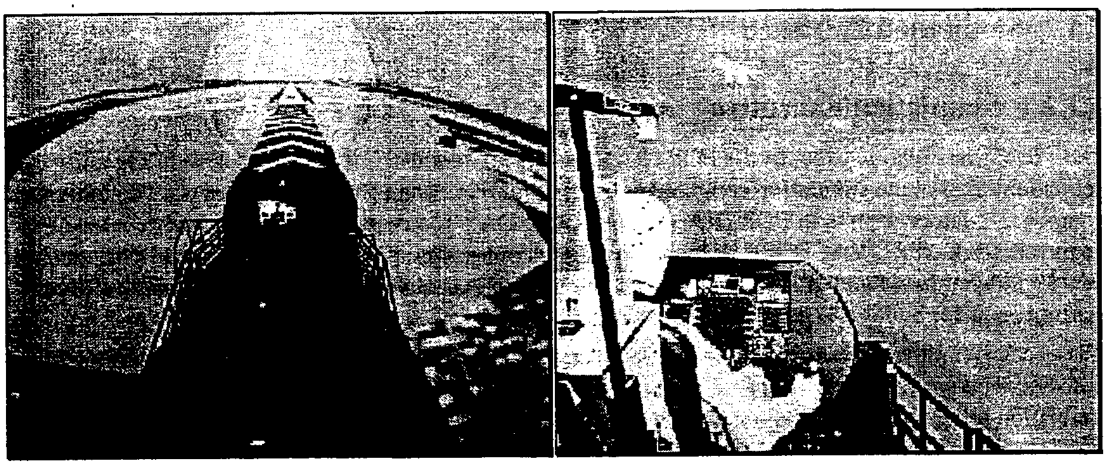


Fig. 3-1 MS-1 Internal Views

3.1.1.2.2 Manned Combat Stations

The Manned Combat Stations consist of a generic cockpit shell platform, highback seat, a high resolution 29" monitor, and F-15 stick and throttle grips. No rudder pedals are incorporated, but there is a footrest built into the cockpit shell. Each MCS is located in its own individual room to keep that station isolated from unwanted ambient light and noise.

3.1.1.2.3 Super Manned Combat Station

The Super MCS is the same as the above described manned combat stations with the following exceptions. The Super MCS has a 53.64° wide by 42.93° high Field-of-View (FOV), high resolution, Out-The-Window (OTW) image projected onto the wall in front of the cockpit. This image is also generated by an Evans & Sutherland 4530 image generator and is video key-mixed with a HUD/EFOV graphics prior to being projected at the simulator station. This provides the Super MCS with OTW visuals and a HUD, neither of which are found in the standard MCS. The Super MCS also has a newer cockpit shell design modeled after the F-22 cockpit ergonomics, but using the F-15 stick and throttle grips like the other manned combat stations. Two pictures of this station can be seen in Fig. 3-2.

Fig. 3-2 Super MCS Views

3.1.2 Simulation Software

3.1.2.1 Simulation Executive

The TRACE simulation executive is FORTRAN based software that allows for the scheduling and activation of all of the simulation components across multiple computers and processors. The individual components can be written in FORTRAN, C, C++, or ADA. The executive software was developed by engineers from AFRL/VACD and Halifax, the on-site contractor, and is updated periodically to incorporate new facility hardware and/or software. A basic simulation executive shell is maintained and used as a starting point for building nearly all in-house simulations.

The executive allows the simulation operators to create schedules for all of the simulation components based on whole, even multiples of the base simulation frame rate, which is 33.3333 ms in the TRACE simulation (30 Hz). Various combinations of schedules can be saved and reloaded as needed for a given simulation test. The executive also allows the simulation operator to turn on/off all of the various processors that are utilized by a given simulation. A system of menus and data files have been implemented to allow the operator to load in various initial conditions for each simulation run. These data files include information on aircraft positions, velocities, fuel load, weapons load, waypoint data, etc. and can also be saved and reloaded as needed by the operator.

One modification that was made to the standard executive for the TRACE simulation was the ability for our simulation to receive an Execute Command PDU from DASA across the network. The AFRL/VACD simulation would sit in its initial condition state until this PDU was received and then it would begin running real-time without the in-house operator commanding this locally. This gave us the capability to synchronize the start of the simulation test runs with DASA. Other than that modification, the simulation executive remained essentially the same as all of our other in-house simulations.

3.1.2.2 Simulation Models

3.1.2.2.1 Aircraft

The aircraft model that was utilized in the TRACE simulation was a 5 DOF, unclassified performance model of an F-15C. This model was written in FORTRAN and originated from McDonnell Douglas in support of the ICAAS simulation program. The model has internal indexing that allows for up to eight aircraft to be simulated from a single process. The maximum number of aircraft simulated for the TRACE tests at the AFRL/VACD facility was four. No digital aircraft were simulated on the US side.

3.1.2.2.2 Radar / IFF

The AFRL/VACD simulation facility was in the process of integrating a new radar model into the simulation environment when the TRACE tests occurred. Because of this, only a subset of the APG-63 radar system was available for use. Only the Track-While-Scan (TWS) mode was available and Doppler effects were not yet included. The IFF system was a simplistic identification model that returned truth data for FFN ID and aircraft type for all radar tracks. The effects of terrain were also not incorporated in the radar model, although DASA did provide AFRL/VACD with a routine to determine if line of sight between objects was blocked by terrain. For the purpose of the TRACE tests, a constant radar cross section (RCS) was agreed upon to be used at all times by the sensors, regardless of target aspect.

The radar model is an adaptation of the Eidetic Radar Model. It contains most of the original code, but uses a different detection algorithm. It is also written in the C++ programming language, which allow multiple instances of radar's. All of the radar calls are by methods of the radar class. Object control is through an array of all players in the simulation. An object or player may or may not have an associated radar.

3.1.2.2.2.1 Initialization

Simulation interface is through common memory called datapool. Datapool contains all object's state data, the radar sensor settings, the radar track data, and other simulation related data. Upon initialization the following happen:

a. A radar is instantiated for each player that has a radar.
b. The sensor data is read which initializes each radar.
c. The radar track data variables are initialized to a clear state. There are multiple methods to instantiate each radar so it will be associated with the correct player.
d. The initial radar scan is started by positioning the antenna to its start position.
e. The radar ran in Track While Scanning mode. This allows multiple targets tracks and a lock on for a selected target.

3.1.2.2.2.2 Execution

The operation portion of the radar is controlled by 5 distinct steps. These steps are updated every frame. Every instantiated radar executes these loops each frame.

a. The radar sensor data is read for possible changes in the functionality of the radar.
b. The next operation is to calculate this radar's signal strength at the target. This is used for the ownship's detection of targets and for other object's radar warning returns. These are represented in an array which is a member of the radar class. These values are written to datapool as radar track data as the last operation of the loop.
c. State data is used to calculate the relative geometry of each possible target. Each player's state data is read from datapool and the corresponding math operations are performed. Some of those operations are azimuth, elevation, range to target, azimuth from target, elevation from target and others.
d. The radar loop is entered. This is a series of operations that determine if this radar detects a target and if the target information will be made known to the pilot. The radar antenna scans a defined scan volume. This is done in increments as the antenna is moved through the scan volume. These questions are asked for each of these segments:
    1. Is the beam looking at the target; i.e., is the target in the scan volume?
    2. Is the object detected; i.e., what is the signal strength value? If the signal strength value is within a set limit, the target is considered to have had a hit. It is necessary for three consecutive hits to establish a track. Five consecutive misses constitute a track loss.
    3. The target's signal to noise ratio is calculated for detection consideration.
e. The radar beam is incremented in the scan volume.
f. The radar track information is written to datapool. If the object is within the scan volume, but out of range, the object is not reported as detected to the pilot. However, the calculated signal strength for each target is placed in datapool. This is used for RWR warning by other objects.

3.1.2.2.2.3 Radar Signal Patterns and Radar Detection

In this simulation it was attempted to model the radar detection as accurately as possible. The radar detection issue is a matter of concern. What manner of detection closely models a real radar, and should detection only occur if the target is within the defined scan volume? There appear to be three basic considerations that determine signal detection:

- What is the maximum range at which a signal can be detected?

  The maximum range could be ambiguous because another factor is the radar cross section of the target . If the range is set, a different radar cross section should alter the returned signal, but with the range set it would not matter.

- Where does the signal to noise ratio equal one?

The signal to noise ratio would depend on the receiver being modeled.

- What is the minimum level for a signal to be detected?

  A set level for detection. Covers the differing range and radar cross section values.

The minimum detection level was used for the TRACE project. This level was set at 100 micro watts at the target as calculated by the transmitting radar. The formula used is:

$$signal = \frac{fact1 * RCS}{fact2 * R^4}$$

where:

$$fact1 = P_{peak} * T_P * PRF * L_a * \lambda^2 * G * G_{rcvr}$$

P_{peak} = peak power
G = gain
G_{rcvr} = receiver gain
L = loss
L_a = Antenna efficiency loss
T_P = pulse width

and

$$fact2 = 4\pi^3 * N_{rcvr} * T_O * k * BW$$

T_O = receiver temperature (290K)
BW = bandwidth
N_{rcvr} = receiver noise
k = Boltzmann's constant.

This gives a radar emission pattern of a constant circle surrounding the emitting radar. To emulate the radar lobes more closely a sync(x) function was added to the formula. This provides a main lobe emanating in the direction the antenna is pointing with several side lobes also present. The graph below is a representation of the main lobe. The sync(x) signal provides a value of 0.0 to 1.0. This applied to the signal calculated using the above formula and because of the nature of the sync(x), the main lobe becomes apparent. We held radar cross section at a constant at 25 square meters because of network constraints. The values used are:

radar cross section	25 square meters
peak power	3000 watts
pulse width	2.4 e-6 seconds
prf1	950 hz
prf2	3000 hz
prf3	125000 hz
main lobe loss	0.03
wave length	0.03
gain	3800
receiver noise	15.0
receiver temp	290.0 K
band width	10.0 Mhz
range	40.0 nm.

These values represent generic radar parameters. Peak power, gain, and radar cross section were values supplied by DASA to make the two radars uniform.

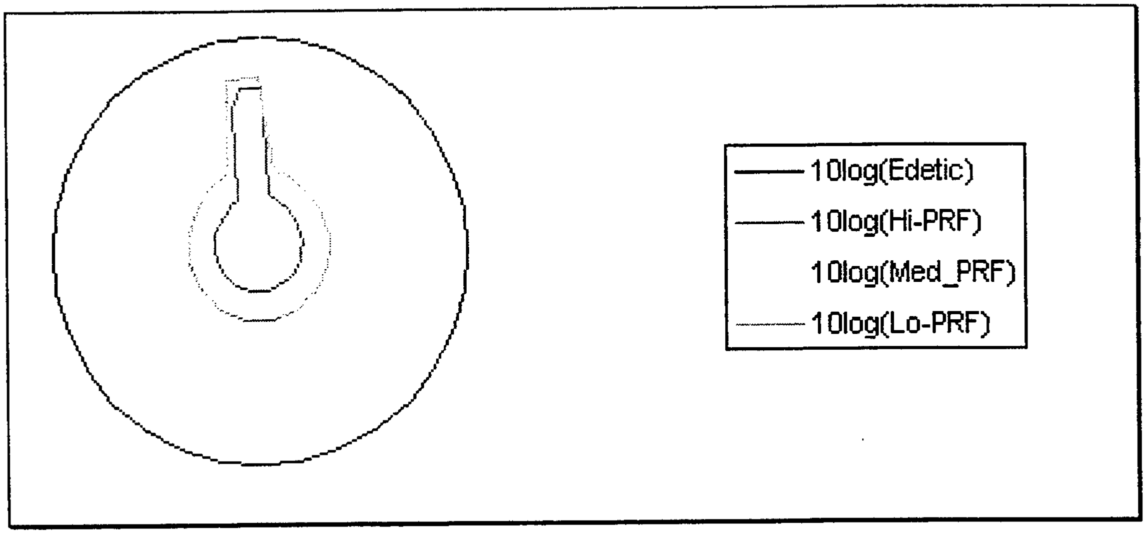


Fig. 3-3 sync(x) effect on emission pattern

Chart Explanation:

This chart is the visual representation of how the sync(x) modifies the original Edietic model radar pattern. The pattern looks very symmetrical and that is because this is plotted with only 36 points. If more points are added, additional side lobes become apparent. This plot is to show the overall effect. The antenna of the radar is in the center of the large circle and is pointing up. This is a 360 degree representation of the radar model emission pattern. The values used are those identified above. The 10log(Eidetic) is the original 360 degree pattern that would emanate from the center of the circle. The other three plots are emission patterns effected by the sync(x) signal. Three pulse rates are used to show the difference is range coverage.

This diagram demonstrates the validity of using signal strength for detection as well as field of view. The advantages of the sync(x) signal is a way of modeling a radar signal pattern with a main lobe.

3.1.2.2.3 Weapons

The TRACE simulation utilized three different weapon models during the TRACE development and test phases: medium range missile (MRM), short range missile (SRM), and 20mm gun. The two missile models were provided by DASA to AFRL/VACD as part of a data exchange agreement with the TRACE program. The gun model was provided to DASA from AFRL/VACD, also as part of the data exchange agreement. The exchange of these models allowed the simulation engineers to employ the same weapon models on both ends of the networked simulation. This created somewhat of a baseline from which to proceed. All weapon flyouts were performed locally at the firing aircraft's simulation site. The only exception to this was the implementation of the flare effects model. Release of flares by a target aircraft caused activation of the flare effects model at the firing aircraft's simulation site, which typically was on the other side of the network from the target. All kill determination was also performed at the weapon activation site with the results being transmitted to the target's site upon completion. The capabilities of each weapon as well as the operational implementation of the weapons in the simulation is described in the following sections.

3.1.2.2.3.1 Missiles

The TRACE missile models provided by DASA were designed as stand-alone models for a single aircraft only. Therefore, each aircraft in the simulation required its own missile model process to be run on separate

processors within the simulation environment. The models that were controlled by these missile processes are described in the following sections.

3.1.2.2.3.1.1 Missile Launch Envelope

The missile models provided by DASA included the appropriate missile launch envelope (MLE) routines for determining the different effective launch ranges based on predefined target evasion criteria. The launch ranges computed are defined as follows:

Nomenclature	Missile	Definition
Rmax1	MRM / SRM	Target performs 3G turn at end game
Rmax2	MRM	Target performs 6G turn and run at range to go < 10 Km
Rmin	MRM / SRM	Minimum range for missile arm

These MLE data were determined and updated as long as certain minimum conditions were met as described in the following sections.

3.1.2.2.3.1.2 Medium Range Missile

The medium range missile model is an unclassified, generic version of an advanced, medium range air-to-air missile (AMRAAM). The requirement for firing an MRM is the ownship has to be tracking the target with radar as the primary designated target (PDT). If so, MLE data is computed and displayed on the HUD to let the pilot decide when to fire the missile. The model incorporates the capability of the missile to achieve an autonomous state, meaning it is capable of tracking the target aircraft with sensors onboard the missile without requiring a guidance beam from the launching aircraft. The point at which the missile becomes autonomous depends on the relative state data between the missile and the target. The point at which the missile goes autonomous is indicated to the pilots on the situation display so they will know when they no longer need to illuminate that particular track with the onboard radar for that particular missile.

3.1.2.2.3.1.3 Short Range Missile / Flares

The short range missile model is an unclassified, generic version of an infrared seeker based missile similar to the AIM-9 Sidewinder. The requirement for firing an SRM is the ownship has to be tracking the target with radar as the PDT and the SRM seeker has to have IR lock-on detection. If these two conditions are met, MLE data is computed and displayed on the HUD to let the pilot decide when to fire the missile. The IR Seeker lock-on is indicated to the pilot by a lock on tone in the headset as well as a change in the SRM symbology on the HUD. Once fired, the SRM immediately becomes autonomous and no longer requires ownship guidance. The model also includes flare effects to allow for implementation of countermeasures. The flare model itself is built in to the missile model and is processed for each SRM as flares are released by the target aircraft.

3.1.2.2.3.2 Gun

The gun model used in the TRACE simulation is an unclassified, generic 20mm gun model that was indexed to be able to process bullet flyouts for up to eight different aircraft in a single process. The requirement for firing the gun is the ownship has to be tracking the target with radar as the PDT. If so, a lead computed optical sight (LCOS) reticle position is computed and displayed on the HUD to indicate where the bullet would be at the target's range had it been fired one time of flight ago. Maximum effective bullet time of flight was defined as 1.5 seconds. The gun model counts bullet hits and accumulates P_k values for the target aircraft until a value of 0.80 is reached; at which point the target is declared killed.

3.1.2.2.4 Missile Warning

The AFRL/VACD TRACE team was not able to get the radar warning receiver (RWR) integrated prior to the piloted tests so a generic missile warning sensor was incorporated to give the pilots information about

when they were fired on by a radar guided missile. This sensor activated warning lights on the cockpit panel that indicated the ownship was being fired on by a radar missile. No information on missile range to ownship or azimuth data was provided to the pilot unless the ownship was tracking the launching aircraft on radar at the time of launch. If so, a red dashed line would appear connecting the ownship symbol on the situation display to the target aircraft that launched the missile. If the ownship lost the launching aircraft as a track while turning away to defeat the missile, the dashed line would disappear. The warning lights remained on until the missile hit or failed and its flyout completed no matter what the ownship's radar track status was. No warnings are provided to the pilot for IR missile launches.

3.1.2.3 Displays and Controls

3.1.2.3.1 Head Down Display

This section gives general descriptions of the major components of the Cockpit 2000 main instrument panel display as shown in Fig. 3-4. This display is presented to the pilot as a single graphic format on a high resolution 29" monitor.

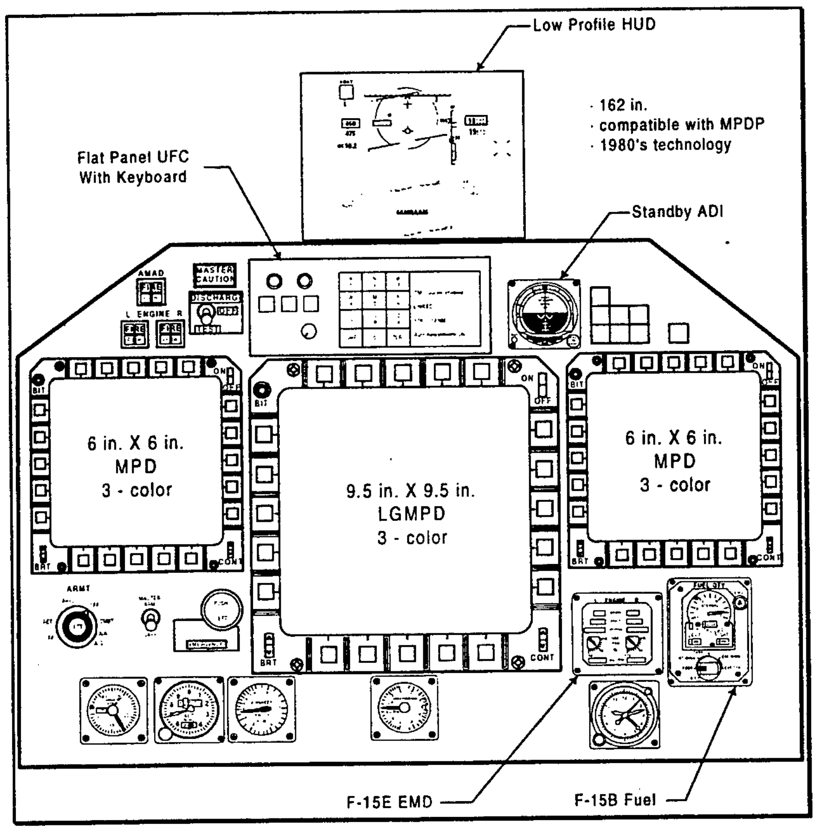


Fig. 3-4 Cockpit 2000 Display

3.1.2.3.1.1 Description and Function

The Main Instrument Panel includes two 6 x 6 inch multipurpose displays (MPDs) and a large 9.5 x 9.5 inch multipurpose display, all of which will have 8-color capability. The eight colors used are red, yellow, green, blue, cyan (light blue), orange, white, and magenta (light purple).

Multipurpose Displays - All symbol color coding complements shape, size, and dynamic (e.g., flashing) codes. Color coding aids quick interpretation of complex formats such as the A/A Sensor display in

realistic scenarios and it contributes to an easy, accurate assessment of the tactical situation. Symbol shapes and color coding are covered in more detail in later sections.

Large Multipurpose Display - This 9.5 x 9.5 inch display is similar to the MPDs, but it has 2 1/2 times more area than the 6 x 6 inch MPDs, providing an inherent declutter feature.

Display Sequencing - To simplify operation each MPD has been programmed to provide direct access to display formats via the HOTAS stick castle switch.

3.1.2.3.1.2 Instruments

The TRACE simulation cockpits are similar to most modern combat aircraft in that primary flight information is located on a HUD in each station. This information is augmented, however, by a standby Attitude Direction Indicator (ADI) ball next to the upfront control, a Vertical Velocity Indicator (VVI), Angle of Attack (AOA) meter, Altimeter and several warning lights on the instrument panel.

3.1.2.3.1.3 Multipurpose Display Formats

3.1.2.3.1.3.1 Air-to-Air Sensors Format

The A/A Sensors format provides a familiar interface with the radar. Its purpose is to display targets and weapon attack parameters. The A/A Sensors format shown in Fig. 3-5 is normally located on the right MPD, but can be selected on the center MPD using the castle switch or on any MPD by selecting from the main menu. This azimuth versus range display is very similar to that of the F-15E with its APG-70. Displayed target symbols represent radar track files only since an IRST sensor was not implemented in the TRACE simulation.

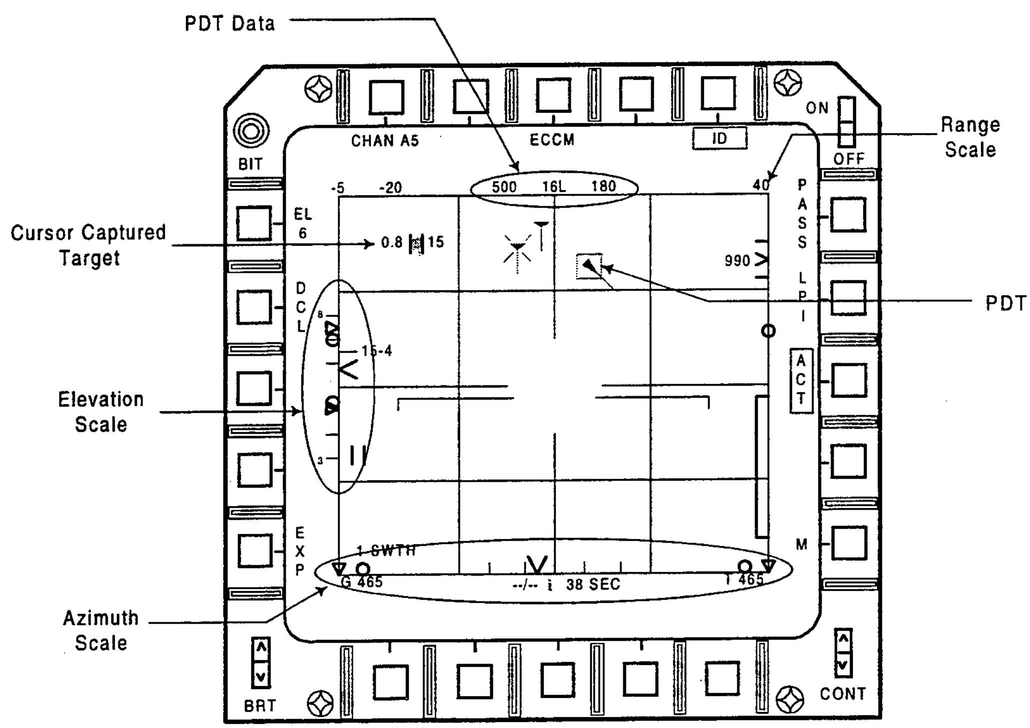


Fig. 3-5 A/A Sensors Display Format

3.1.2.3.1.3.1.1 Target Symbols

Target symbology for hostile, friendly, and unknown targets, as well as PDT and Next Shot, are represented (Fig. 3-6).

Hostile Threats - Targets positively identified as threats are shown as red triangles. The shape of the triangles further indicates whether the target is a fighter or bomber.

Unknowns - If a target can't be identified by aircraft type it will be shown as a box. An unknown may be identified as hostile by other means, in which case it will be colored red. A complete unknown will be yellow.

Friendly - Other than ownship, friendlies will be green circles with heading vectors.

Heading Vector - A target's heading vector is displayed as a line segment originating from the symbol's "nose." Any target's heading can be estimated by comparing the orientation of this vector with ownship.

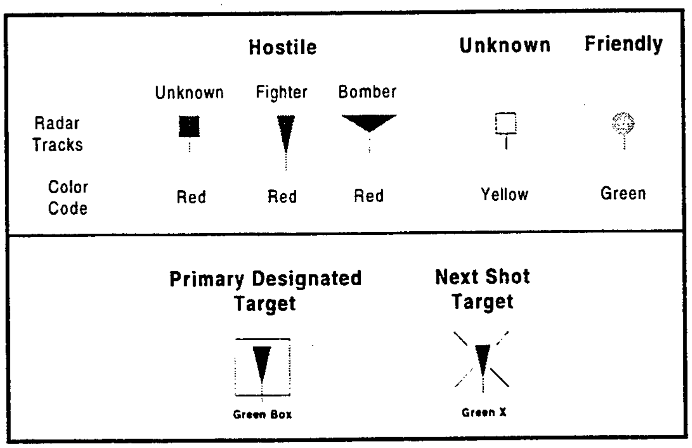


Fig. 3-6 Target Symbology

3.1.2.3.1.3.1.2 Grid Lines

The horizontal grid lines divide the format into four equal sections which helps the pilot estimate range based on the selected scale. Vertical grid lines that help show target azimuth are drawn at 0 degrees and ± 30 degrees. The left and right edges of the grid represent azimuth field of regard limits of ± 60 degrees which encompasses the capability of the radar.

3.1.2.3.1.3.1.3 Elevation Scale

Along the left edge of the grid a scale is provided that represents ± 30,000 feet of altitude. The altitude of a track is shown digitally to the right of the track symbol when a target is cursor captured.

3.1.2.3.1.3.1.4 Azimuth Scale

Along the bottom edge of the grid an azimuth scale is provided. Tic marks are shown every 10 degrees until ± 30, then again at ± 60 degrees. Circles show the left and right azimuth angle limits of the radar. The vertical lines on the display indicate azimuth lines from the ownship. Targets pointing straight down at any azimuth and range are actually pointing right at the ownship. This is the same as the standard B-scope type radar display used in many current combat aircraft.

3.1.2.3.1.3.1.5 Acquisition Cursor

This symbol incorporates the cursor functions of cursor capture, range selection and display selection control. "Cursor capturing" a target provides altitude and airspeed data adjacent to the captured target. The cursor bars are solid if assigned to this format, and dashed when assigned to another MPD.

3.1.2.3.1.3.1.6 Range Scale

Shown above the upper right corner of the grid, this indicates the range in nautical miles from the bottom to the top of the grid. Ranges of 10, 20, 40, 80, 160 and 320 nm are selectable by bumping the top or bottom of the grid with the acquisition cursor. Bumping range on this format does not affect the other formats.

3.1.2.3.1.3.1.7 Ownship Data

Calibrated airspeed and altitude (in thousands of feet) are displayed to the left and right of the ownship symbol respectively. A pitch and bank indicator is provided in the center of the format to aid the pilot in head down aircraft control.

3.1.2.3.1.3.2 Situation Display

The Situation Display format is very similar to the air-to-air sensors format with the following exceptions. The viewport layout is designed as a top down view of the ownship and its surroundings with track locations positioned by azimuth and range. A compass rose encircles the ownship symbol for referencing heading data and the scenario waypoints, if any, can be viewed by selecting the route (RTE) button on the left side of the display. The range scale of the display is controlled by range bumping or by toggling the range scale up or down from the range control buttons on the upper right hand of the display. The Situation Display uses two range rings centered on the ownship for range reference lines; one at half of the current display range and the other at full display range. Indicated range is measured from the ownship symbol to the top edge of the display. Tracks are positioned in azimuth on the display along imaginary radial lines that are measured relative to the ownship longitudinal body axis as opposed to the implementation of the B-scope azimuth view scheme found on the A/A Sensors format. Ownship pitch and bank indicators are not included in the Situation Display format. All other target and ownship information is presented in the same manner as the A/A Sensors format, including target symbology, ownship data, cursor capturing, etc. An example view of the Situation Display format can be seen in Fig. 3-7.

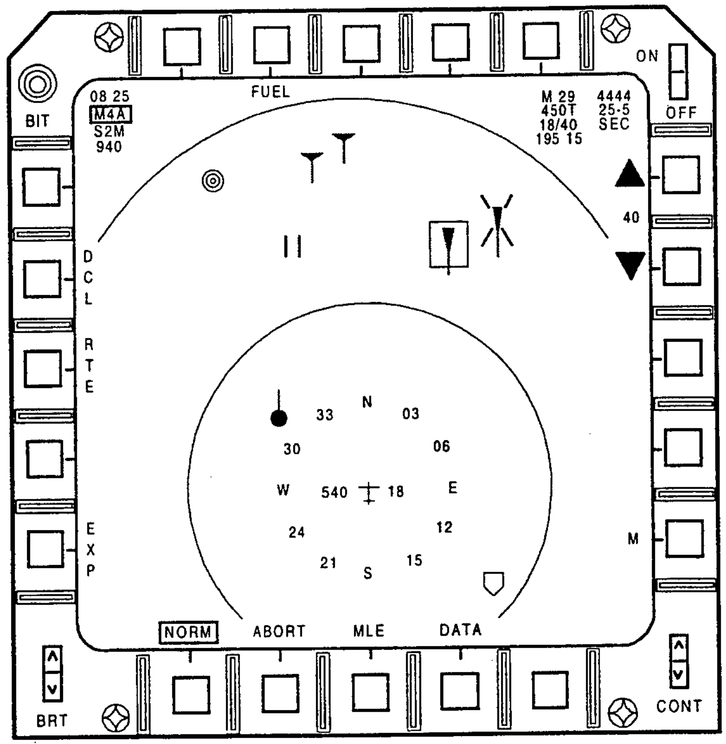


Fig. 3-7 Situation Display Format

3.1.2.3.1.3.3 Weapons Format

The weapons (WPNS) format displays status of ownship weapons, fuel, and countermeasures (Fig. 3-8). Digital readouts for gun rounds, fuel (lb.), chaff, and flare are provided along with graphical depictions of the SRMs and MRMs on board the aircraft. MRMs are color coded with yellow lines and yellow fill while the SRMs utilize red lines and red fill. The filled missile symbol indicates which missile is the next one of that type to be fired, while hollow missile symbols indicate number of additional SRMs and MRMs currently on board. After a missile is fired, the graphical symbol for that missile is removed and the next missile of that type to be fired is filled.

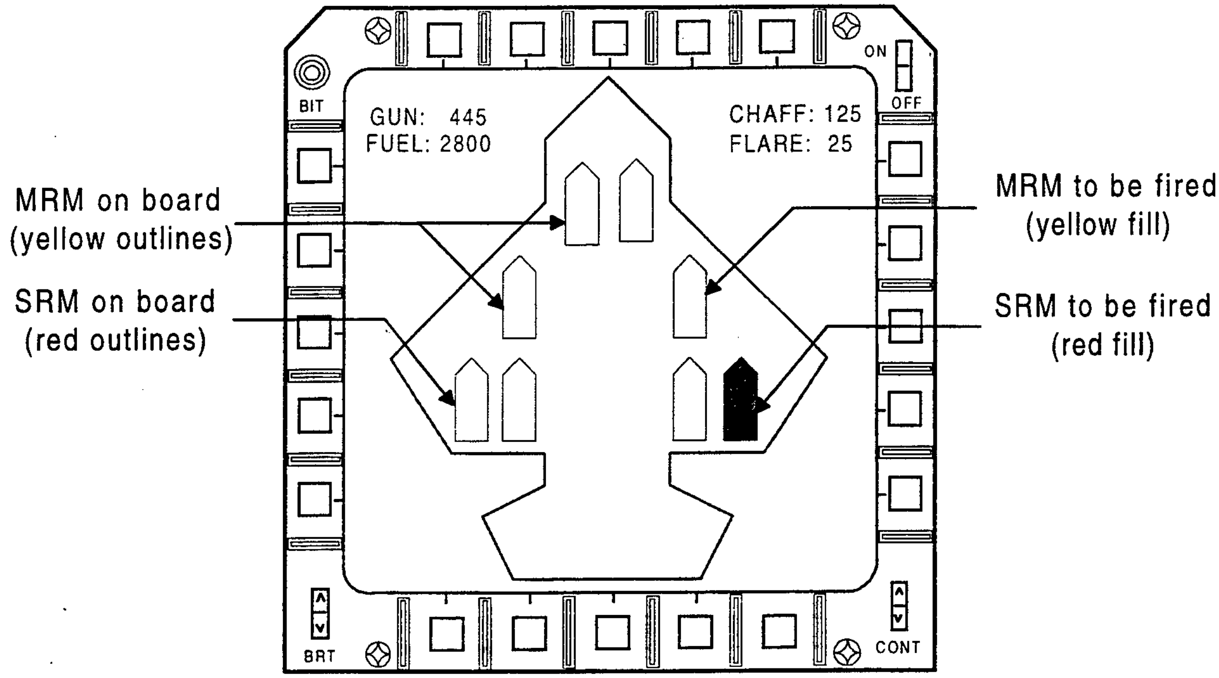


Fig. 3-8 Weapons Display Format

3.1.2.3.2 HUD Symbology

The HUD symbology is basically the same as the F-15E HUD symbology with some modifications to reduce clutter and to meet research simulation needs. MRM, SRM and Gun modes are all supported. An example view of the HUD used in the TRACE simulation can be seen in Fig. 3-9.

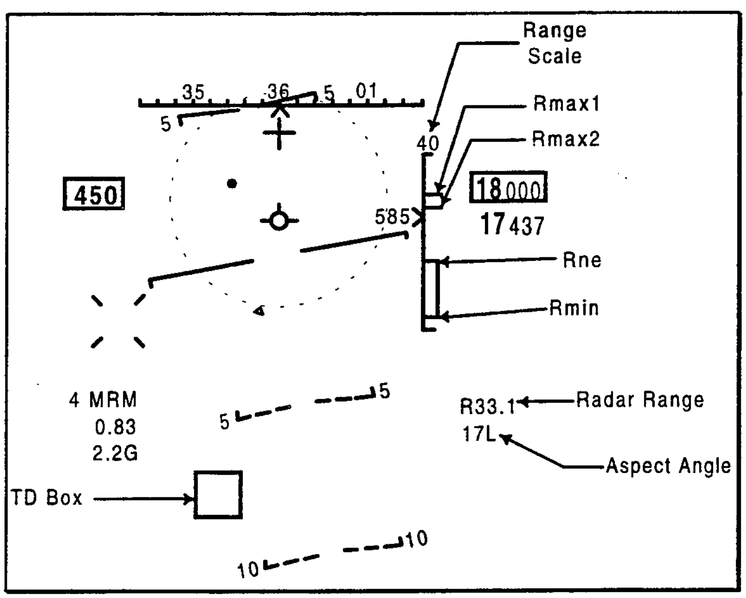


Fig. 3-9 HUD Symbology

3.1.2.3.2.1 MLE Scale

The HUD MLE scale will automatically change ranges so that Rmax is located between full and half range, regardless of PDT range.

3.1.2.3.2.2 Shoot Cue

This cue is positioned below the TD box and appears when all conditions for a valid missile shot are satisfied. The MRM shoot cue is a star and the SRM shoot cue is a triangle.

3.1.2.3.2.3 Next Shot Cross

The open cross symbol functions similar to the TD box, except it indicates the position in azimuth/elevation of the "next shot" target. The "next shot" target is where the PDT box will move to upon the next quick step command by the pilot.

3.1.2.3.3 Expanded Field of View Display

The MCS displays incorporate a unique capability called the Expanded Field of View (EFOV) display concept. The EFOV concept provides the pilot with the capability to visually track an aircraft which is Within Visual Range (WVR), but is not in the field of view of the monitor. An EFOV symbol appears at the edge of the screen for each aircraft that is within 5 NM of the ownship. A detailed description of these EFOV symbols and how they work is presented in section 3.1.2.3.3.1 of this document.

The MCS display has three different display views available at any time during the simulation that are toggled by pressing forward on the castle switch located on the stick grip. The first view is the cockpit 2000 main instrument panel described in section 3.1.2.3.1. The second view (Fig. 3-10) is the full EFOV display. The EFOV display consists of EFOV symbols and a generic sky/earth grid with HUD overlay. The third view (Fig. 3-11) is a split screen of the EFOV display on top and three MPDs from the main instrument panel placed at the bottom of the monitor.

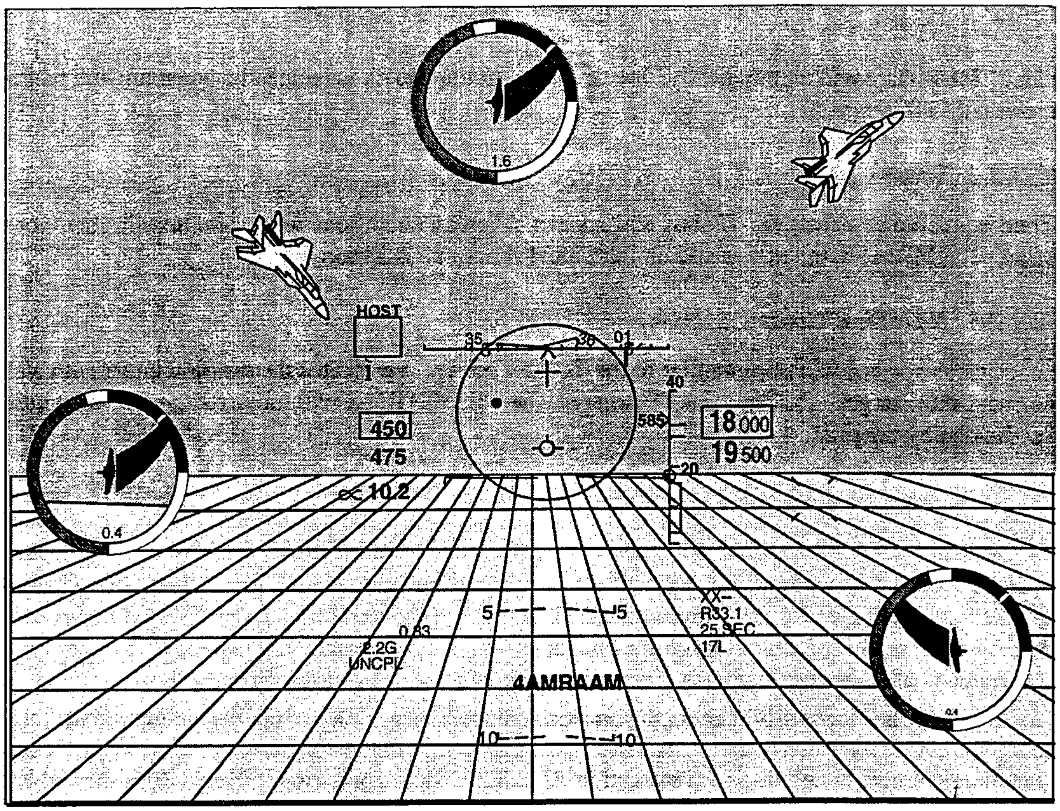


Fig. 3-10 Full EFOV View

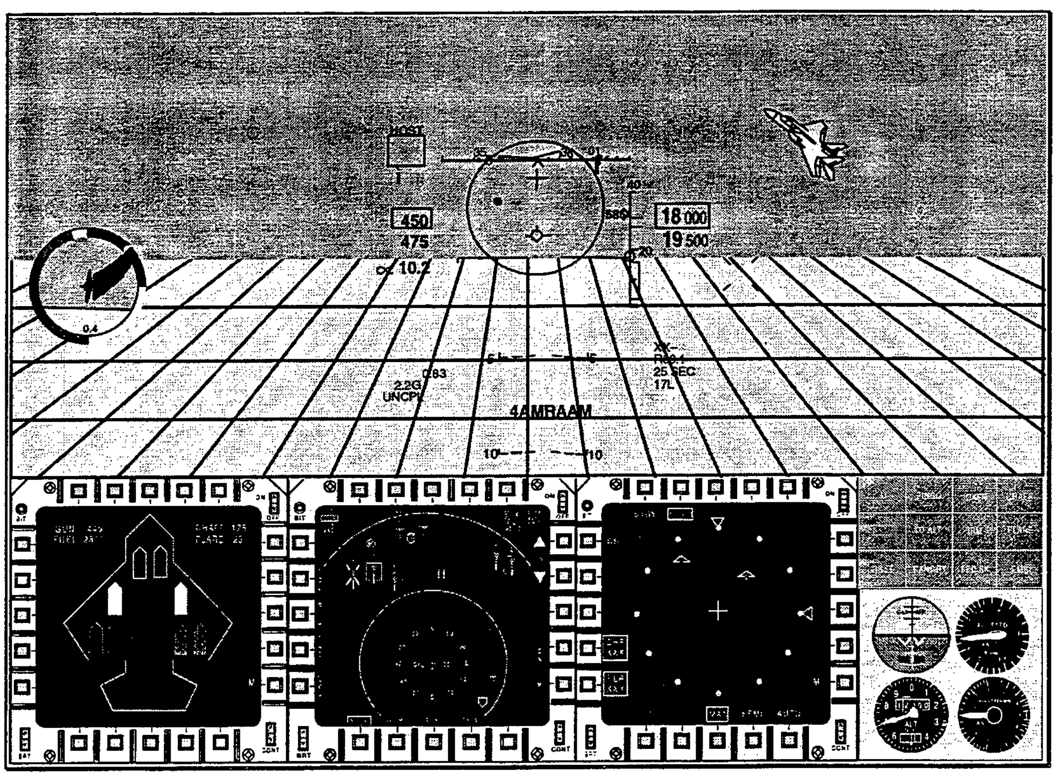


Fig. 3-11: Split EFOV/HDD View

3.1.2.3.3.1 EFOV Symbol

The EFOV symbol appears on the monitor when a WVR aircraft is not in the field of view of the monitor. Fig. 3-12 defines the different parts of the EFOV display circles. The EFOV symbol travels around the outside edge of the monitor field of view. The symbol is drawn in the appropriate roll plane of the target. The EFOV symbol incorporates a sky/earth background with the target and other essential cues. If the target is below ownship, the ground will show as the background. If the target is above ownship the sky will show as the background. The EFOV symbol varies its size based upon the range from ownship to target. The closer the target is to ownship the larger the EFOV symbol will be. This also can provide the pilot with range rates.

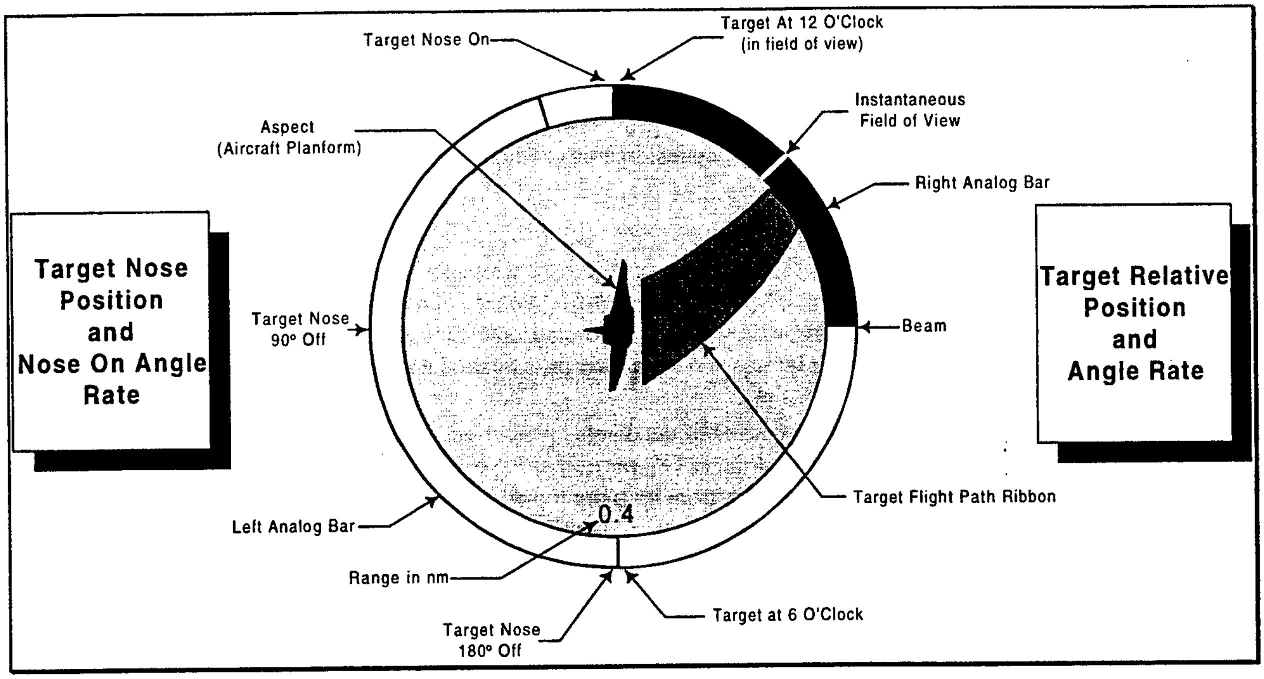


Fig. 3-12 EFOV Symbol Definitions

The EFOV symbol is not displayed if the target is masked by the ownship. That is if the target is beneath the belly of the ownship the EFOV symbol would not be displayed since the pilot would physically be unable to see the target.

Multiple EFOV symbols are displayed when required. If multiple targets are in the same roll plane the EFOV symbols are overlaid with a slight offset. The EFOV symbols are prioritized by range when overlaid except the PDT which would always be on top. If an EFOV symbol contains the PDT then the outline of the circle is color coded red.

Left Analog Bar: The target nose position analog bar on the left side denotes the position of the target's nose relative to ownship: when the bar is at the bottom (i.e., little to no bar) it means the target's nose is 180 degrees off or tail on to you. If the bar is half way, it means the target's nose is 90 degrees off. When the bar is full or all the way at the top, the target's nose is pointed at you. As the bar moves up or down, the rate at which the bar moves gives the target's nose rate.

Right Analog Bar: The target relative position analog bar on the right side shows the target position relative to ownship's nose. If the bar is full or at the bottom, the target is at your 6 o'clock. When the bar is halfway or at the beam position, the target is abeam at 9 or 3 o'clock. If the bar is small or approaching the top, the target is approaching the instantaneous field of view (i.e., the monitor screen) or the front field of view. As the bar hits the instantaneous field of view marker the EFOV circle will disappear from around the target and the target will be free of the EFOV symbol until it moves beyond the field of view of the

monitor again. The rate at which the bar moves gives the pilot nose rate. (The phantom bar is only shown as representative bar travel and does not appear on the actual display.)

Instantaneous Field of View Mark: The instantaneous field of view mark is located at the 17 1/2 degree point up the target relative position analog bar for a 29" monitor. This mark represents the point at which the target will appear on the monitor.

Range Display: Gives the range between the ownship and the target. It can also give rough closure rates to the pilot via range changes.

Aspect/Aircraft Planform: The aircraft view or picture of the aircraft gives the actual orientation of the target if the pilot were to turn his head and look at the aircraft. The target's attitude would let the pilot know the target's aspect, shows the target going away if the pilot sees the tail and closing or threatening him if he sees the target's nose, etc. The display has a sizing model which shows the targets actual size based on range.

Target Flight Path Ribbon: The target flight path ribbon indicates the target's past flight path, this also shows on the monitor front field of view, since the pilot uses the target's flight path as the primary reference to perform his basic fighter maneuvers against that target during close-in combat.

3.1.2.3.3.2 Split EFOV/HDD View

The split EFOV/HDD view (Fig. 3-11) provides the pilot with a split screen of the full EFOV view, three MPDs from the Cockpit 2000 display, a basic set of flight instruments, and warning lights. This single display format provides the pilot with sufficient information to perform typical air-to-air combat tasks. This display format would normally be selected unless the pilot desired more detailed information from the full EFOV view or Cockpit 2000 display.

The out the window EFOV view portion of the display provides the same capabilities as the full EFOV view. However, the field of view of the EFOV portion of the display is reduced in the vertical plane from 30 to 22 degrees by dropping 4 degrees from both the top and bottom edges of the full EFOV view. This window is then translated vertically up in order to make room for the MPDs at the bottom.

The MPDs in the HDD portion of the display provide the same capabilities as the MPDs in the Cockpit 2000 display. However, the size of the MPDs is reduced to allow them to fit in the bottom portion of the split screen display. Also added to the HDD portion of the display were a basic set of instruments and warning lights. The instruments that are represented include ADI, Airspeed, Altitude and Vertical Velocity indicators. The warning lights that are functional are AI, SAM, Bingo fuel, Joker fuel, Low Altitude, Chaff release, Flare release, and Speed Brake extension.

3.1.2.3.3.3 Full EFOV View

The objective of the full EFOV view (Fig. 3-10) is to provide the pilot with the required situational awareness to fly and fight using a manned combat station display on a 29" monitor with a field of view having 35 degrees in azimuth and 30 degrees in pitch (Fig. 3-13). The full EFOV view consists of

1) an out the window view with a earth grid and blue sky,
2) HUD symbology overlaid on the out the window view,
3) moving models of aircraft and missiles when in the field of view of the 29" monitor,
4) gun tracers, and
5) the EFOV symbol.

The EFOV symbol provides the pilot information on other aircraft outside of the field of view of the monitor display, but which would be in the field of view in a full 360° field-of-view dome.

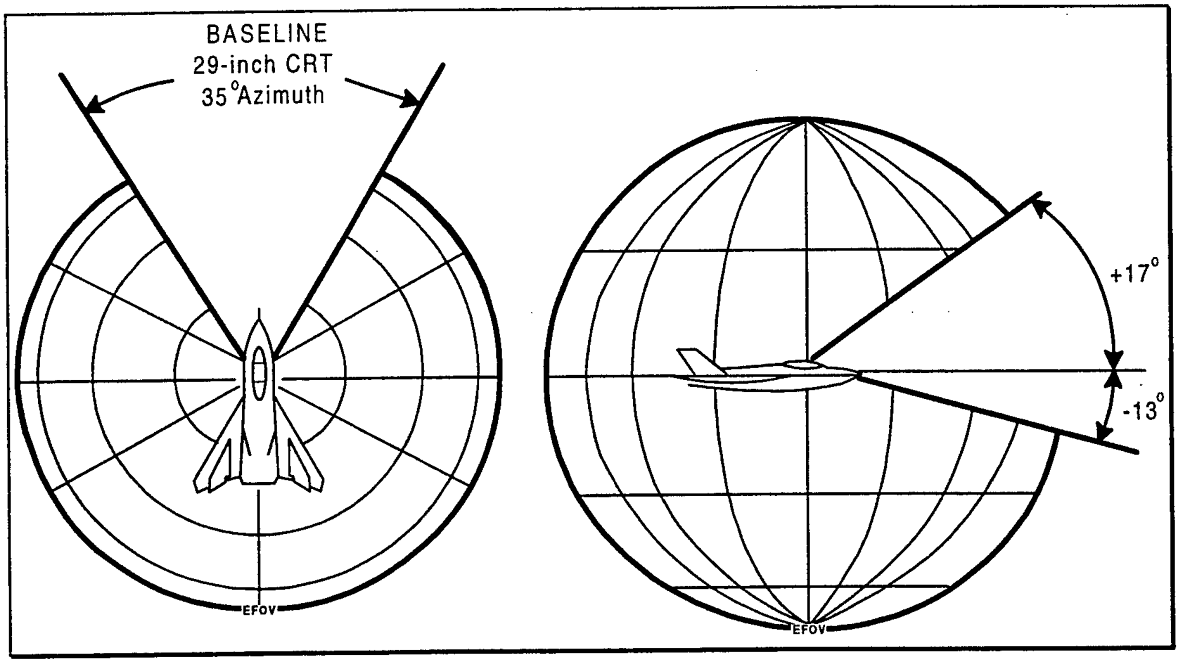


Fig. 3-13 EFOV Field of View

3.1.2.3.4 HOTAS

The F-15E stick and throttle grips (Fig. 3-14) are used to provide the switchology needed for control of the simulated aircraft systems. They provide the pilot immediate access to control of the displays when it's not appropriate to use the bezel push-button.

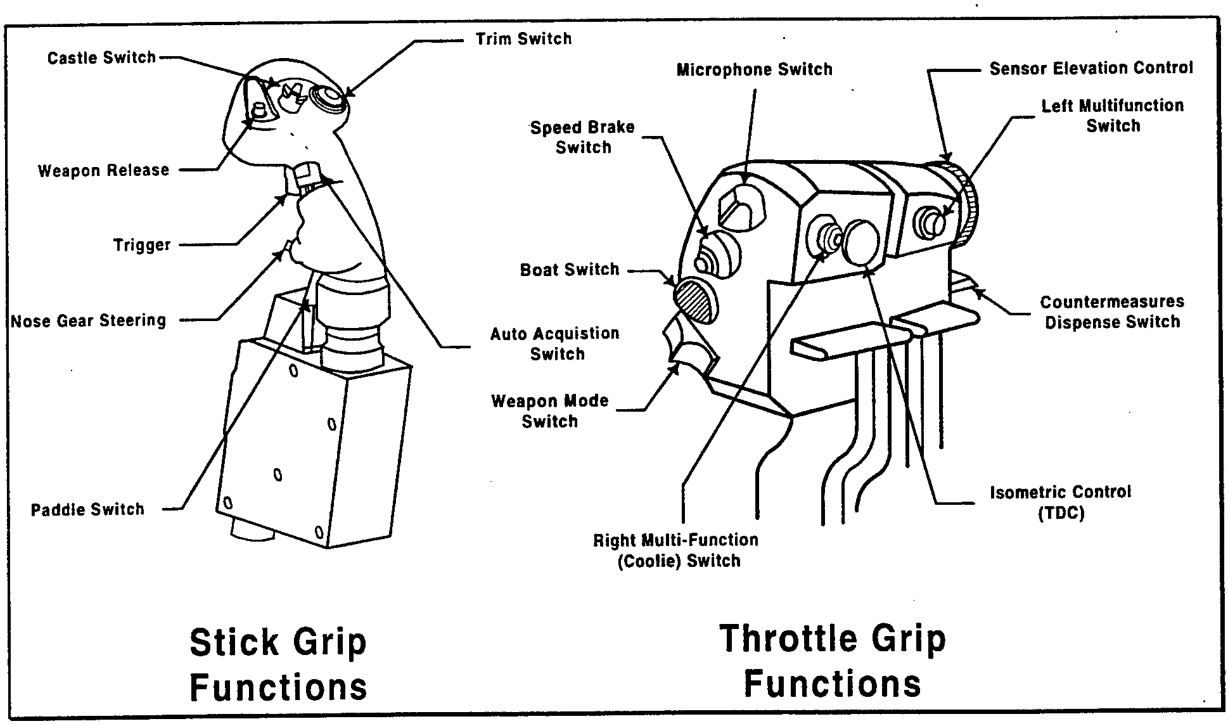


Fig. 3-14 F-15E HOTAS

3.1.2.3.4.1 Flight Controls

The center control stick and throttles provide aircraft control as in the F-15. Rudder pedals are not functional.

3.1.2.3.4.2 HOTAS Switchology

3.1.2.3.4.2.1 Throttle Controls

This section describes the throttle switch functions as depicted in Fig. 3-15.

Countermeasures Dispense (CMD) Switch - This three-position toggle switch is spring-loaded to (center) OFF. Pushing down commands on flare to be dispensed program.

Target Designator Control (TDC) - The TDC is an isometric positioning device with a depressable action switch. It moves the acquisition cursors left-right and up-down on the A/A Sensor Display format at a rate proportional to the amount of force applied.

When the TDC is pressed with the cursors on one of the perimeter options on a display, that option is commanded as if the push-button next to it were pressed.

The TDC can be used to change a display's range scale by moving the cursors to the top or bottom of the display causing the range to "bump" to the next value in that direction. The TDC is also used to maneuver the cursor for cursor capturing targets.

Right Multi-Function Switch (Coolie) - The Coolie is a four position switch. Clicking up for less than one second quick steps the PDT to the Next Shot target (if one exists).

Speed Brake Switch - This is also a three-position switch. The forward position is retract, the center position is hold, and the aft position is extend. The switch will remain in any selected position. If the Angle of Attack (AOA) is above 25 units, the speed brake will not extend when selected. It will automatically retract when AOA increases through 25 units. When AOA is reduced, the speed brake will automatically extend, provided that the switch is still in the extend position.

This switch is also used to control landing and takeoff functions in the simulation. The switch should be aft for landing and forward for takeoff in order for the pseudo gear model to function properly.

Weapon Select Switch - This three-position slide switch primarily controls weapon selection. The forward position is for Medium Range Missiles (MRM), the center is for Short Range Missiles (SRM), and the aft position selects the 20 mm gun.

Gear Switch - This two position switch on the base of the throttle is used to extend and retract the landing gear for simulated takeoff and landing conditions.

3.1.2.3.4.2.2 Stick Controls

This section describes the stick switch functions as depicted in Fig. 3-16.

Castle Switch - The castle switch is a four-way toggle switch with a fifth (pressed) position. Left, right, and aft movement cycles the MPD/LGMPD programmed displays

The pressed position is used when assigning acquisition cursors. To assign the cursors to a display, first depress and release the switch, then (within one second) cycle toward the intended display. Only one display may have the assigned cursor at a time.

Weapon Release Button - This button is depressed to launch missiles.

Gun Trigger - Full action fires the gun when in gun mode.

Nose Gear Steering - This button will double the nose gear steering gain as long as it is held in. Once released, steering gains return to their normal values.

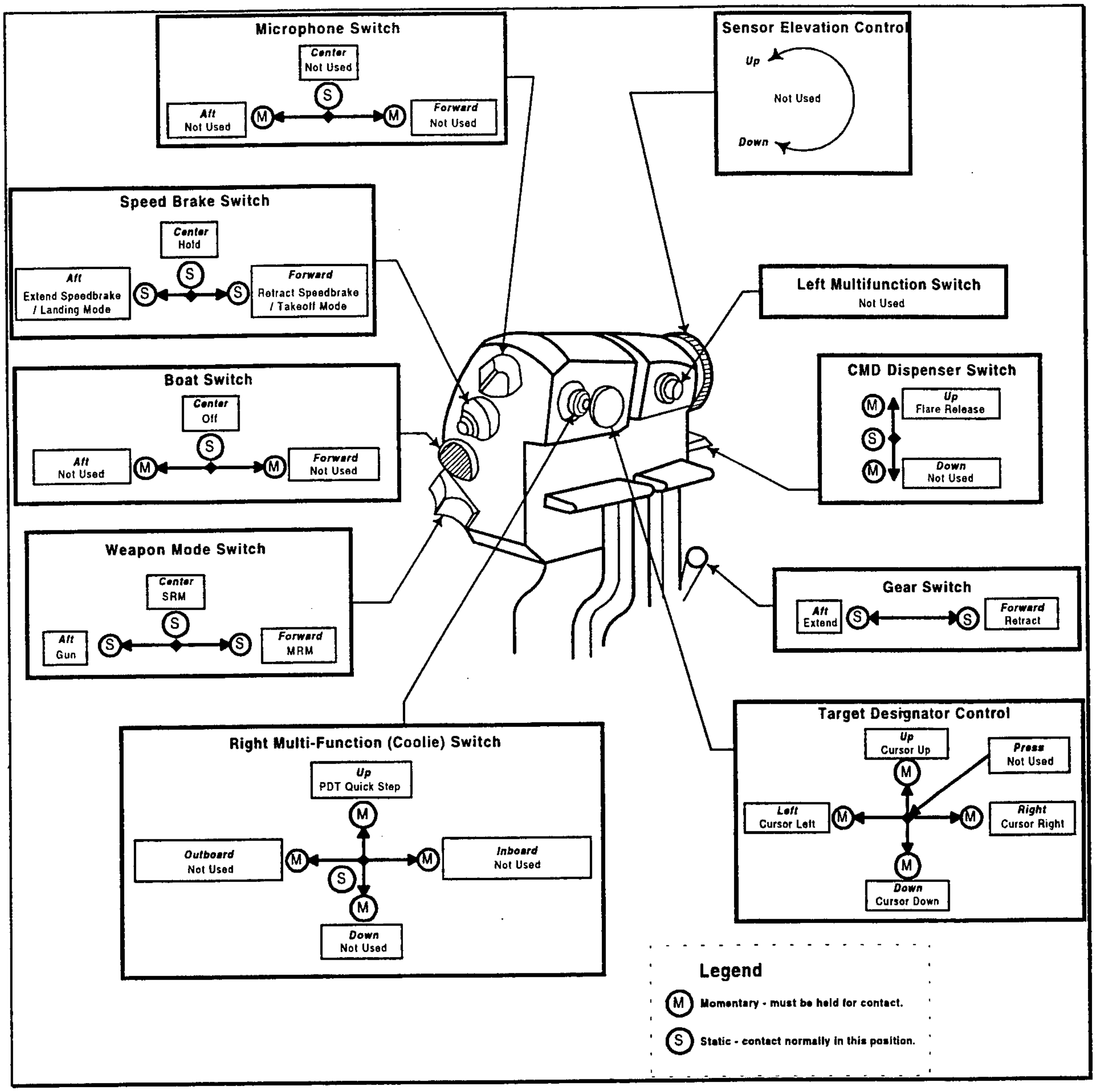


Fig. 3-15 Throttle Switches

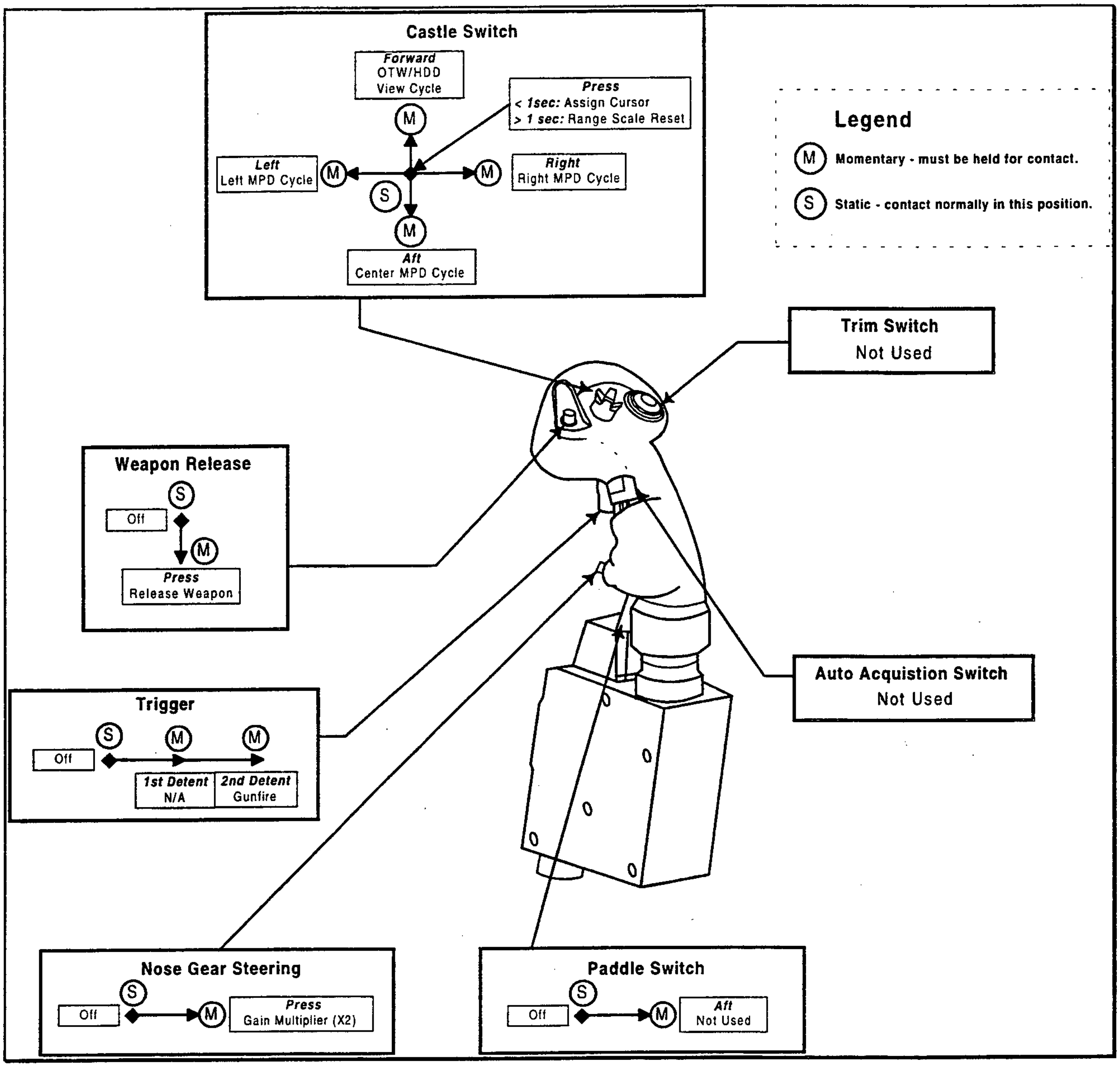


Fig. 3-16 Stick Switches

3.1.2.3.5 Virtual Battlefield Management System

The TRACE simulation utilized the Virtual Battlefield Management System (VBMS) to allow the operators and spectators to view the entire simulation scenario from various perspectives during individual test runs. VBMS can also record all of the simulation data in real-time and save it to separate files to allow each run to be replayed at a later time, if desired. VBMS encompasses a wide variety of other features that are useful in research simulations, but those features will not be discussed here. Some example screen shots of VBMS can be seen in Fig. 3-17.

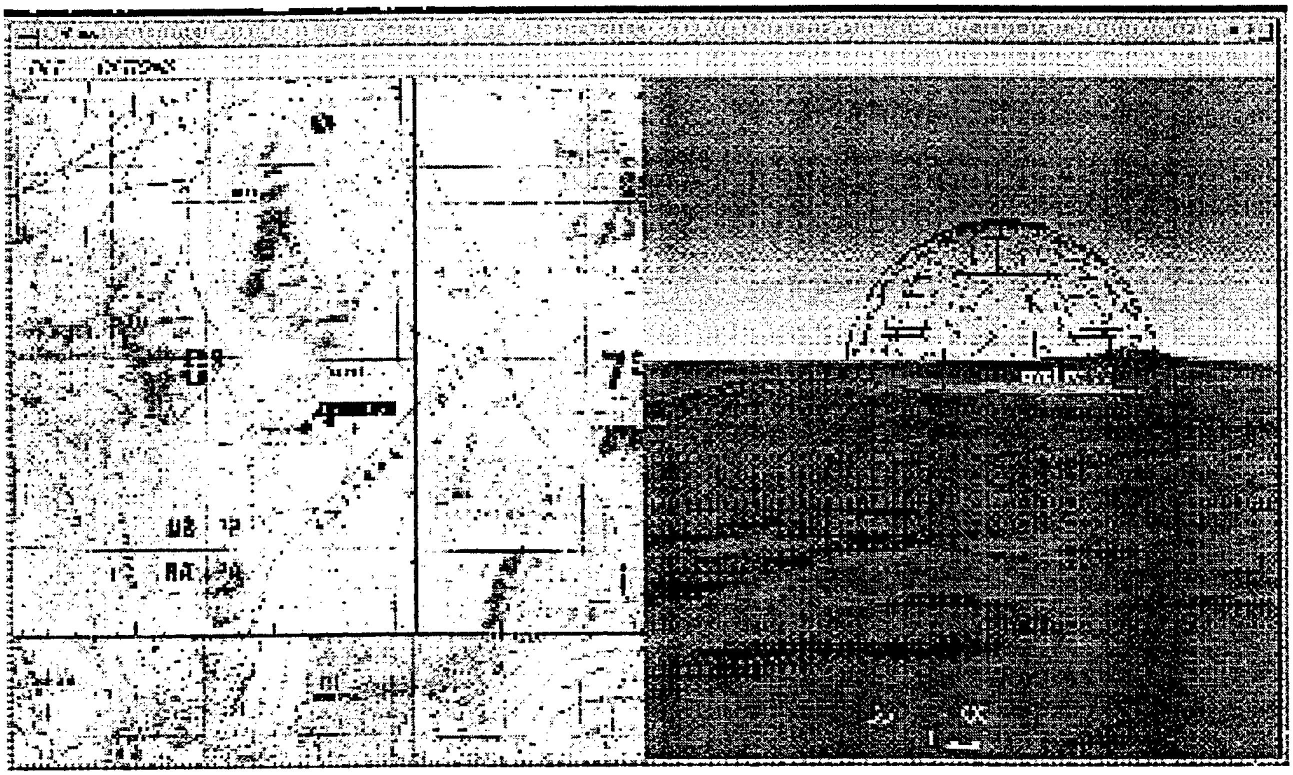


Fig. 3-17 Virtual Battlefield Management System Display

3.1.2.4 Network Software

Two separate computers were used for the AFRL Network Interface Units (NIUs). A Silicon Graphics Challenge XL computer which contained eight R4400 200 MHz processors, a SCRAMNet card and a built-in Ethernet port was used as the main interface to the network. It also contained an SGI VME E-Plex board for increased Ethernet connectivity. This board was connected to the I/O backplane and contained eight individual Ethernet ports. Due to the direct backplane connection, the E-Plex option had the same capability as eight separate Ethernet cards. The DASA protocol NIU was implemented by the DASA NIC which was supplied by DASA and described in 3.2.3. The AFRL interface from the Encore simulation to the NIC was through SCRAMNet to a process on the Challenge then through SCRAMNet to the NIC. The DIS and DIS-Lite protocol NIUs were implemented completely on the Challenge and communicated with the Encore through SCRAMNet. All the processes running on the Challenge were isolated to a single processor using Silicon Graphics' real-time extensions to their IRIX operating system.

3.1.2.4.1 Encore Interface Software

The Encore synchronously exchanged simulation data with the Challenge through SCRAMNet. Each frame of the simulation the Encore would read state data about the DASA entities from SCRAMNet and put it into DATAPOOL and after the local models were done it would write state data about the ARFL entities into SCRAMNet and trigger the NIU interface process on the Challenge to run. This software was independent of the network protocol.

3.1.2.4.2 Challenge NIU Software

The Challenge NIU software implemented the DIS and DIS-Lite protocols using a version of Mäk Technologies VR-Link that was modified by Mäk to implement DIS-Lite. It was synchronized with the Encore simulation by two logicals in SCRAMNet that were set by the Encore. The first was set just after the Encore simulation received its frame interrupt so that the frame times could be synchronized and the GPS time of the start of the frame could be obtained. The second was set after the aircraft and missile

models were done to trigger the network sends and receives. Conditional compilation was used to compile the DIS-Lite version.

3.1.2.4.3 NIC Interface Software

The AFRL NIC interface software was implemented on the Challenge and utilized the NicSimInterface routines as described in chapter 3.2.3 to communicate with the NIC. This process was synchronized with the Encore in the same manner as the DIS NIU.

3.1.2.4.3.1 SCRAMNet Data Map

The data map for the communications between the Encore and the processes running on the Challenge was laid out as a large structure containing arrays of structures that mirrored the data needed for the DIS pdus that were used. There were 32 aircraft and weapon fire structures, 80 missile and missile detonate structures, and a 32 by 32 array of radar structures. A C++ class interface, (SimData) to the structure was developed to standardize access to the data. The SimData class was used in each of the protocols interface processes.

3.2 DASA Simulation [DASA]

3.2.1 Simulation Hardware

3.2.1.1 Dome Simulator

The TRACE simulation used two of the Power PC 604 RISC (200Mhz) processors of the simulation computer; one for the simulation executive and aircraft and another one for the weapon system simulation. The simulation executive runs internal within a 40Hz frame, but provides external data within a 20Hz frame. The other modules are running synchronized to the simulation-model.

The following table details what simulation software was running, the rate it was scheduled to run, and the processor where each component was located.

Computer System	Processor #	Software/Process	Rate
Power PC 604	1	Sim Executive	40Hz
		external	20Hz
Power PC 604	1	Weapon System	20Hz
Power PC 604		IG Driver	40Hz

I

Locally, the data was exchanged via a fiber optic SCRAMNet interface

3.2.1.2 VLO-Cockpit Simulator

3.2.1.2.1 Simulation Processors

The TRACE simulation utilized four Force SPARC CPU cards and one FORCE CPU-40 card for the simulation executive and model processing for the TRACE simulation tests. The simulation executive runs internal within a 40Hz frame but provides external data within a 20Hz frame. The other modules run synchronized to the simulation-model.

The following table details what simulation software was running, the rate it was scheduled to run, and the processor where each component was located.

CPU Card	Processor #	Software/Process	Rate
SPARC-5V	1	Sim Executive	40Hz
		external	20Hz
SPARC-2CE	1	Weapon System	20Hz
SPARC-2CE	1	CGT's	20Hz
CPU-40	1	HDD Driver	40Hz
		IG Driver	40Hz
SPARC-5VT	1	Network Interface	variable

3.2.1.2.2 Graphics Computers

The graphics computers for graphic display processing are integrated in the VLO-Cockpit simulation computer on their own CPU card as shown in the table above. This computer handles the cockpit displays, HUDs and HDD's. This CPU card is connected via the VME-Bus over the Shared Memory architecture. It drives the displays with VME-Viper-Cards and/or a by Ethernet connected SGI O_2.

3.2.1.2.3 Image Generator

With the VLO-Cockpit the TRACE simulation used a Evans & Sutherland model 2000 image generator (IG) for controlling the OTW visual scene. The Lake Mead database was used and correlated to that of the

Compuscene IV IG used by the Dome Simulator to ensure that all connected simulators in the network were flying over the same terrain. This image generator was configured to run asynchronously at a 60 Hz frame rate.

3.2.1.3 Computer Generated Target (Weapon Systems)

This software package is designed to simulate aircraft weapon systems in the air to air and air to ground role with simulated pilot behavior and to interact with manned simulators and different Computer Generated Forces (CGF) via a network interface.

The software is running at DASA's simulation facilities on a Harris Night Hawk computer and a SUN Sparc 2 workstation. System specific software is the connection to the real time clock of the platform to enable realtime response and behavior for weapon system and the network interface and the installation of a shared memory, to communicate with the outside world. simulation frame and weapon system software are written in Fortran, the interface software partly in C.

At this time up to 14 A/C weapon systems including sensors and armament can be handled by the software package. This means that 14 participants in any mix of internetted simulators and computer generated A/C can interact at one time. The software is wholly parameterized, so changing one parameter in an include file and recompiling the software increases the possible amount of participants. The only limiting factor is the memory size of the platform.

Six software shells can be identified in the package :

- The simulation frame, connected to a realtime clock of the platform, which controls simulation state and realtime scheduling
- The interface to a dedicated shared memory region of the platform, to communicate with the outside world
- The connection to a digital map to simulate the influence of terrain on Weapon System and to have a common terrain data base with other participants
- The decision making process
- The maneuver generation
- The weapon system

The simulation state can be controlled in three different manners. First by simulation frame itself, second by locally connected simulators via shared memory interface and third by a scenario module via a Network Interface Computer, in which case the simulation state will be controlled globally for all connected players.

There are two ways to initialize the simulation and include it into a complex internetted scenario simulation. In the first case input data files are read in to set up weapon system, mission task, the FLOT (forward line of own troops), way points, armament, expendables and initial state like position and velocity. In the second case a Scenario Module sends via a Network Interface Computer (NIC) initializing data to the simulation.

The software runs in a 50 msec cycle time. How many weapon systems can be simulated on one CPU depends, beside CPU speed, on the role of simulated A/C (the critical one is here the Fighter role). While one simulation cycle for one weapon system including sensors, threat analysis, maneuver logic, autopilot and A/C systems takes about 4 to 4.5 msec, every missile flyout simulation inclusive seeker head operation needs roughly 2 msec. Therefore when 8 Fighter are firing a missile at nearly the same time, one run loop reaches the frame time of 50 msec. When simulating more than 8 A/C in the fighter role, they should be distributed on 2 CPU's.

This holds true for the old RISC processors which are built into the Sparc 2 and Night Hawk. Recently the Night Hawk was equipped with modern Power PC's which run 6 times faster. Taking into account the overhead in the interface routines used to exchange data with the outside world, first trials show that at least 28 Fighters, each firing a missile, can be simulated on one CPU.

Several tasks will be fulfilled by the interface routines, The first is to extract data from the simulation and form Protocol Data Units (PDU's) according the DASA Protocol. The time stamp for kinetic PDU's is composed of the internal simulation time and an adjustment to the realtime clock. This is also done in the

interface of connected simulators and allows a precise extrapolation of incoming kinetic PDU's to internal simulation time. Additionally it helps to compensate for occasional overruns of simulation frame time in the dead reckoning algorithms.

If a NIC is attached to shared memory, every time a new kinetic PDU is sent, the difference between actual data and extrapolated data (if it exists) is faded in over several cycles to get a continuous differentiable data stream. The effect can be seen in the computer generated image (CGI) of the target while flying close formation with it. It is also very important for the Radar simulation since jumps, especially in the location of the target, severely disturb the derivation of velocity and acceleration vectors in the Kalman filter to build up radar tracks and decreases the lock-on range.

3.2.2 DASA Software Module Description

3.2.2.1 DASA Weapon System

An overview of the DASA weapon system is presented in Fig. 3-18. The shaded components were not active during TRACE simulations.

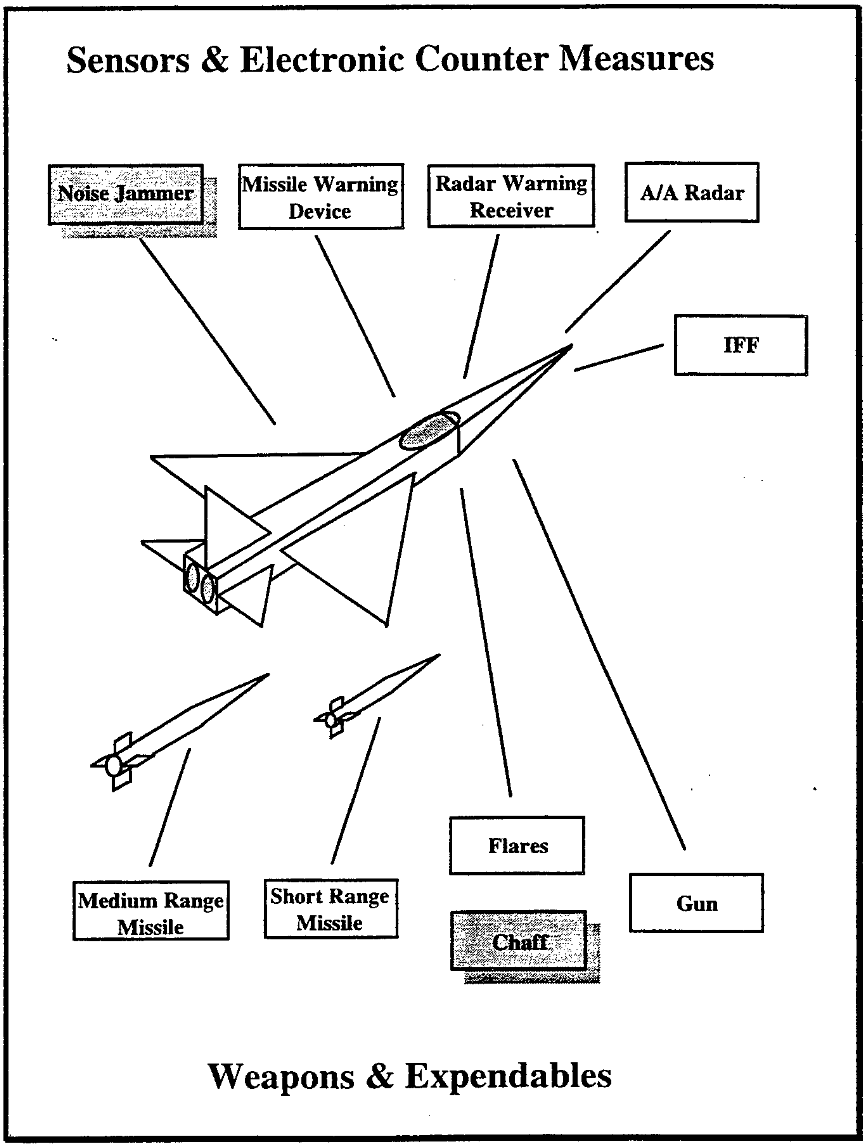


Fig. 3-18 Weapon System Components

3.2.2.2 General Simulation Set Up

The general simulation set up is shown in Fig. 3-19. It describes schematically the set up for the dome simulation. The set up for the VLO - or Integration - cockpit is essentially the same.

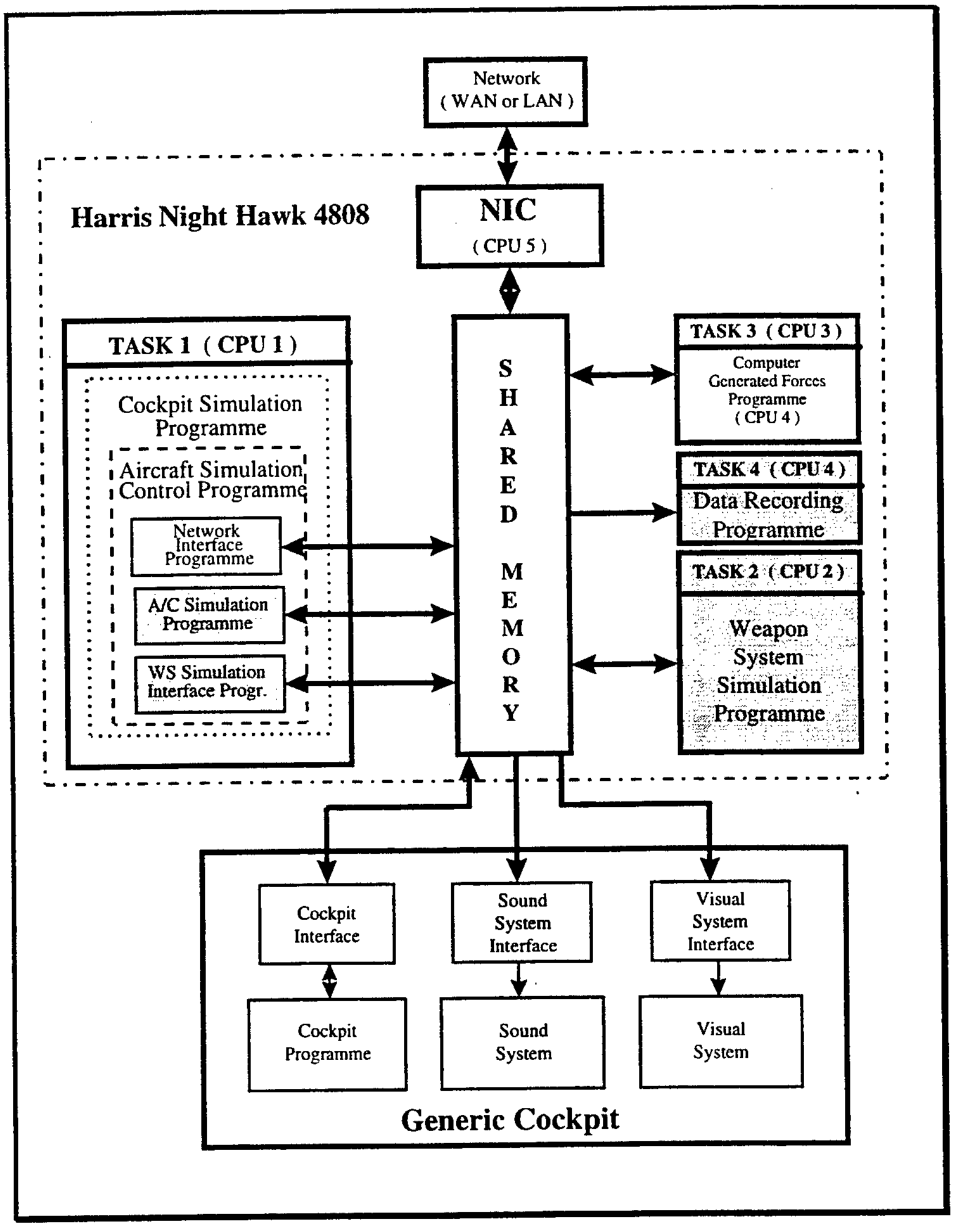


Fig. 3-19 Block Diagram of Simulation Set Up

The simulation tasks are distributed on different CPU's which exchange data via "shared memory".

The cockpit simulation program incorporates the network interface program, the aircraft program and the weapon system interface program (controlling the initialization, correct cycle time and termination of the weapon system simulation). This task runs in a 25 msec cycle. The weapon system simulation program runs in a 50 msec cycle.

Additional tasks included the Computer Generated Forces (CGF) program (also running in a 50 msec cycle) and the Network Interface Computer (NIC) which connected these simulation tasks with the external participants via Local Area Network (LAN) or Wide Area Network (WAN).

An additional task runs on the dome simulation computer only, which is a program that extracts data from the shared memory every second. This data is used to produce plots presented in chapter 12 (**Appendix D - Selected Data Recorded** During Production Runs [DASA]).

Fig. 3-19 illustrates the main weapon system components and the global data flow. These components are:

- Sensor models and their trackfile processing
- Corporate Trackfile (CTF) processing including sensor fusion algorithms, threat analysis and prioritization algorithms
- Man/Machine Interface comprising displays and controls
- Weapons and fire control computations
- Countermeasures such as flares. chaff and jamming.

3.2.2.2.1 Generic Fighter Aircraft Model

The aircraft model used for TRACE simulation is a 6 DOF model (incorporating a detailed flight control system, undercarriage, etc.). It is a design of a delta canard configuration originating from an early version for the European Fighter Aircraft.

The model is written in FORTRAN and was used for the AMS simulation campaign in 1989. Fig. 3-45 illustrates the performance of the aircraft in terms of its 1g - flight envelope, together with its camax - and maximum Mach number boundaries (exceeding this structure limit by more than 5 percent results in an aircraft crash).

3.2.2.2.2 Sensor Models

The sensor suite contains

- A/A Radar of APG 65 class
- Identification Friend/Foe (IFF) of MK XII type
- Radar Warning Receiver (RWR)
- Missile Warning device, producing warnings against Medium Range Missiles (MRM) with radar seeker heads and Short Range Missiles (SRM).

The Electronic Counter Measure consists of a Noise Jammer with either forward or backward jamming capability.

NOTE: Jamming Function deactivated for TRACE project

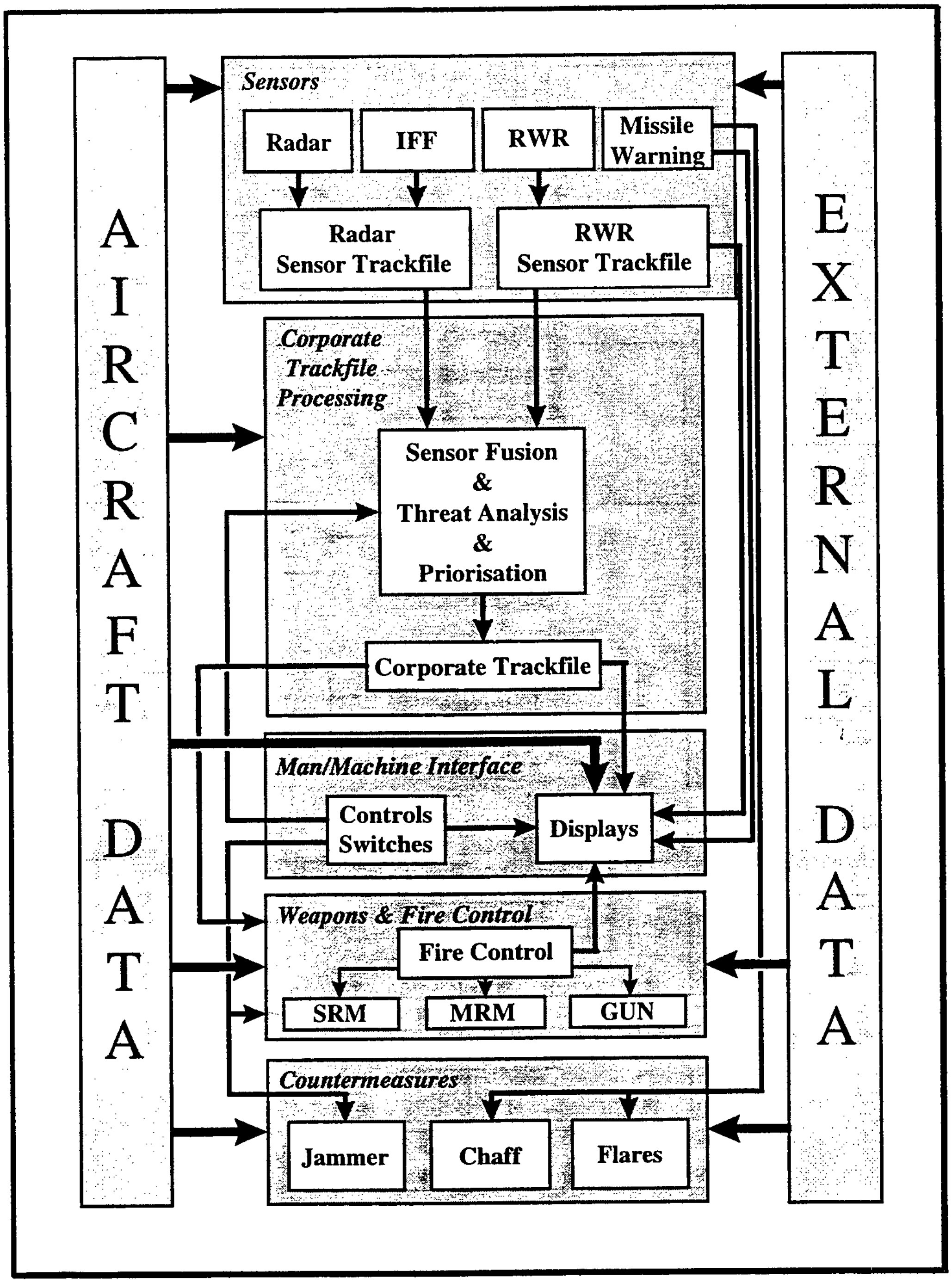


Fig. 3-20 Global Data Flow

3.2.2.2.2.1 Radar / IFF

A block diagram of the radar model is shown in Fig. 3-21.The moding and handling of the radar is automated (radar sensor management) to support the pilot.

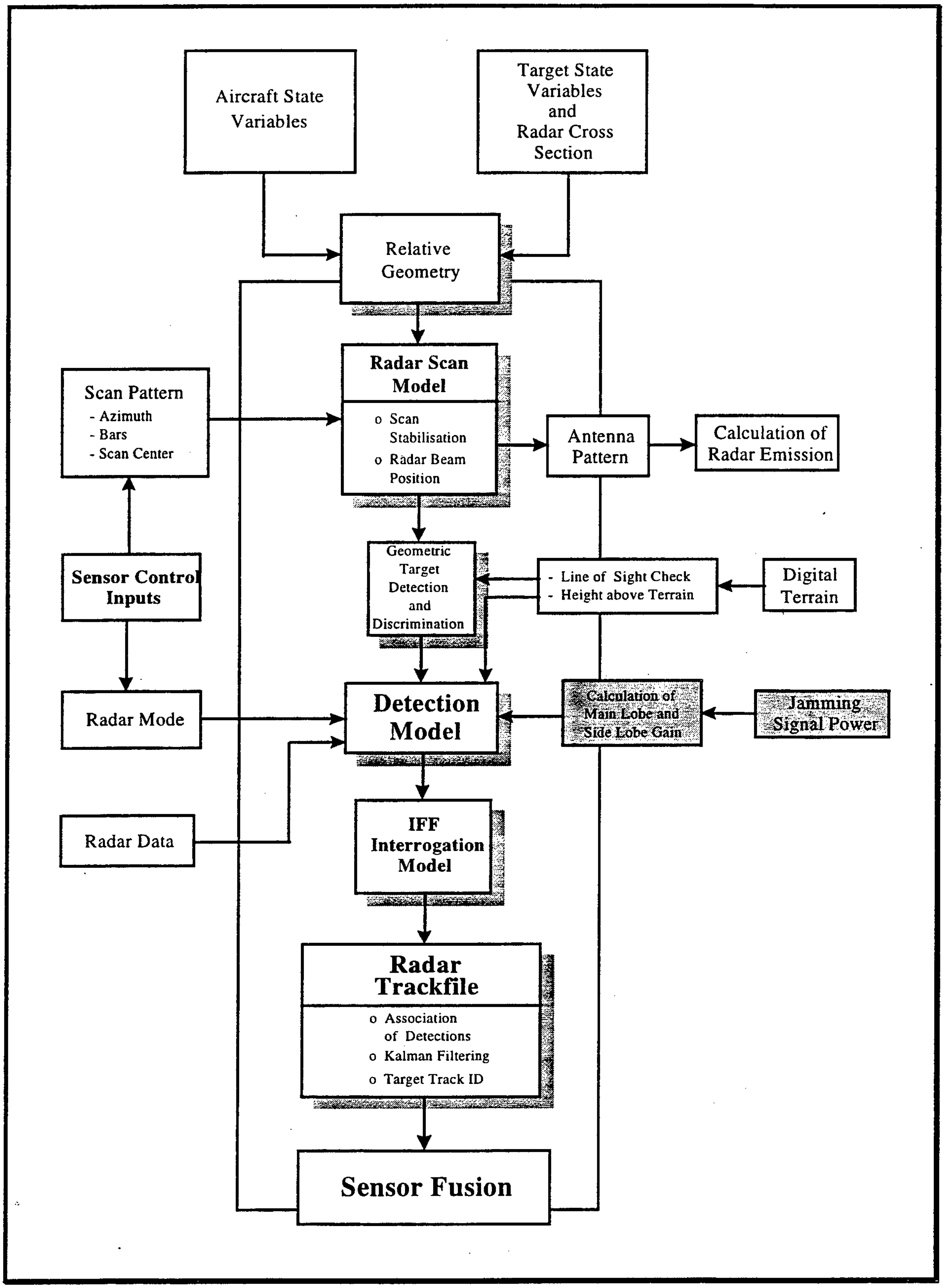


Fig. 3-21 Block Diagram of Radar Model

The following tasks are carried out:

- selection of radar mode (normally Track While Scan, TWS)
- selection of Pulse Repetition Frequency (PRF)
- selection of scan center, azimuth and elevation (normally a scan frame time of more than 3 sec for target tracking will not be utilized, as only then, Kalman filters will produce sufficiently good target data)
- acquisition of targets
- tracking of priority and, if possible, secondary targets
- a search scan ("3 Scan Mode", Fig. 3-36 shows an example for altitude coverage) is normally active, as long as no target information is available (radar detection or RWR detection) , or if in the course of the mission no prioritized target track is present anymore.

Main characteristics of the radar are:

- Gimbal limits
  - azimuth + - 70 degrees
  - elevation + - 70 degrees
- Stabilization
  all search and track modes are stabilized with respect to the horizon.
  HUD Acquisition Mode scan is aircraft fixed.

Scan rate is 65 degrees/sec, except for Single Target Track (STT) which is 100 degrees/sec.

Input data:

- own aircraft state vector (position, velocity)
- target state vector (position, velocity)
- target radar cross section (for TRACE runs constant at 5 square meters)
- LOS check (visible or not visible due to terrain) and height above terrain
- jamming signal, direction and power (not active for TRACE runs)
- MMI or sensor management inputs determining radar mode and scan pattern

Output data:

- radar emission according to antenna gain pattern
- radar trackfile data (including "Lock On" status)
- track identification

Main modules:

- radar scan model which calculates according to control inputs (azimuth, number of bars, scan center)
- scan pattern (horizon stabilized or aircraft fixed) and the actual beam position
- radar emissions to each participant according to antenna gain pattern are calculated, if LOS exists
- geometric target detection and discrimination (including LOS check for target visibility)
- detection model calculates target detection probability according to radar mode, radar data and height above terrain, determined by signal power, main lobe and side lobe clutter, and jamming signal power (according to antenna main lobe and side lobe gains ; measurement errors are added to radar detection values)

- identification Friend/Foe interrogation model
- radar trackfile processor which performs
  - association of detections
  - Kalman filtering of associated tracks to produce trackfile data
  - track identification and determination of "Lock On" status

3.2.2.2.2.2 Radar Warning Receiver

The RWR model covers 360° in azimuth and +/- 90° in elevation with a resolution of +/- 6° in azimuth and +/- 12° in elevation. As an option, the RWR can discriminate between friendly and hostile radars. Detection of friendly radars will not be processed and will therefore not appear on the displays.

Fig. 3-22 presents the block diagram of the RWR model. A special Line of Sight (LOS) check is not necessary, as the senders of emissions will perform this check, and will therefore not send out a radar emission if LOS is obscured.

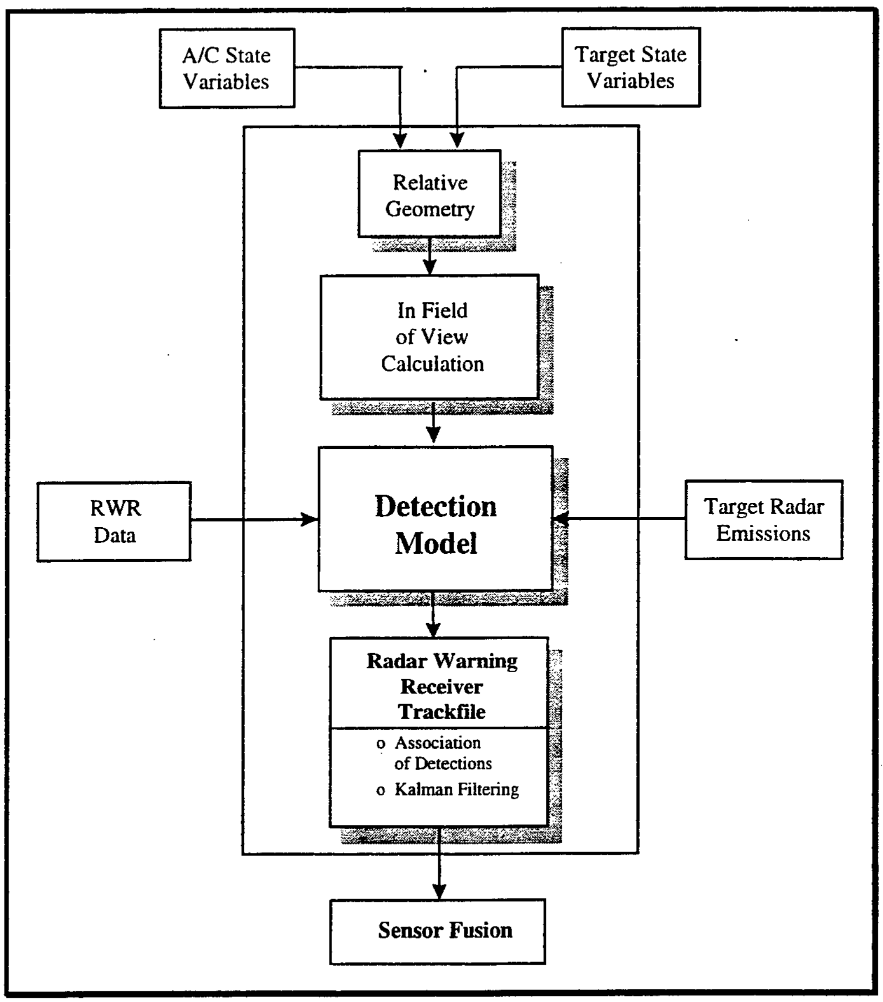


Fig. 3-22 Block Diagram of Radar Warning Model

Input data:

- own aircraft state vector
- target state vector
- target radar emission

Output data:

- trackfile data (direction to emitter)

Main modules:

- "In Field of View" calculation; i.e. can emission be detected by available sensor field of view
- detection model; detection will occur, if predefined signal to noise level of detector is exceeded; measurement errors are added to RWR detections
- radar warning trackfile processor which performs
  - association of detections
  - Kalman filtering of associated tracks to produce trackfile data

3.2.2.2.2.3 Missile Warner

Presently, the generic weapon system has no model for a missile warning device. The warnings presented in the displays are derived from purely geometric considerations, and, in case of MRM, also missile status (i.e. is missile seeker head searching or tracking a target).

The method is shown in Fig. 3-23.

The present range values are:

- MRM: 10 km
- SRM: 5 km.

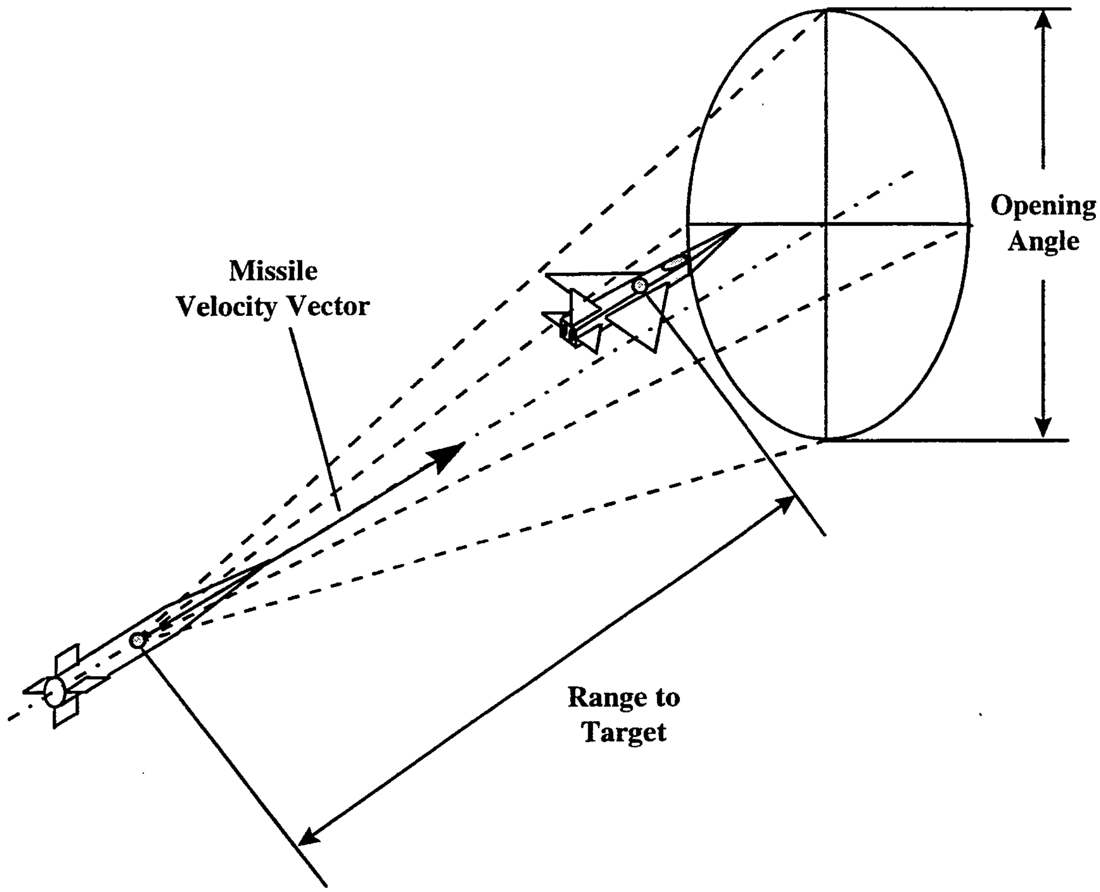
3.2.2.2.3 Weapons and Expendables

The gun model provided by Air Force Research Laboratory was not incorporated at DASA because the necessary software changes in the Head Up display could not be incorporated in time for the production runs and the gun was considered to be a secondary weapon

The weapon system contains:

- Generic Medium Range Missile (MRM), AMRAAM type
- Generic Short Range Missile (SRM), AIM 9L type
- Gun, Mauser MK 27 type

A total of 8 missiles can be carried, any mix of MRM and SRM is possible.



MRM : Missile Warning will be activated, if
- aircraft is within predefined opening angle relative to missile velocity vector
- missile is in autonomous phase (seeker head is open)
- range to missile is less than predefined value

SRM : Missile Warning will be activated, if
- aircraft is within predefined opening angle relative to missile velocity vector
- range to missile is less than predefined value

Fig. 3-23 Missile Warning Criteria

The expendables on board are:

- Flares against SRM
- Chaff against MRM

Flares and chaff deployment is done automatically by the system. A more detailed description of flare and chaff drop will be given later.

NOTE: Chaff is not available in the TRACE project

3.2.2.2.3.1 Medium Range Missile

The block diagram of the Medium Range Missile is shown in Fig. 3-24. The seeker head used in TRACE is not susceptible to chaff. The seeker head lock on range is calculated purely by table look up, depending only on aspect and elevation of the missile to the target.

A LOS check between target and missile is made as soon as the seeker head has lock on to target, height above terrain is continuously checked throughout the flight.

Input data:

- own aircraft state vector (determines missile initial conditions at time of firing)
- radar trackfile data (measured target state vector)
- target state vector and target radar cross section (RCS for TRACE runs not applicable)
- chaff state vector and radar cross section (not applicable for TRACE runs)
- LOS check and height above terrain.

Output data:

- missile state vector
- missile event flags describing its status (e.g. midcourse guidance phase, autonomous phase, hit or miss and termination cause at end of flight, i.e. failure case if miss has occurred)

Main modules:

- uplink model for midcourse guidance phase (during this phase, the measured target data is transmitted to the missile; radar "Lock Breaks" during this phase will initiate extrapolation routines to fill the track loss gap)
- active radar seeker head (at predefined range to target ("hand over"), the missile will acquire the target with its own seeker head and become autonomous; at this stage, target state vector, target radar cross section and, if present, chaff state vector and chaff radar cross section will be the required input data)
- guidance law (which differs for midcourse guidance phase and autonomous phase)
- aerodynamics, thrust and mass model determined by missile performance data
- flight path integration
- miss distance calculation
- hit or miss assessment.

3.2.2.2.3.2 Short Range Missile

The block diagram of the Short Range missile is shown in Fig. 3-25. LOS checks and height above terrain are performed throughout its flight.

Input data:

- own aircraft state vector
- target state vector
- either throttle position and fuel flow (if IR emission is calculated on missile side) or IR emission of target
- flare state vector and flare emissions (if flares have been dropped)
- LOS check and height above terrain.

Output data:

- missile state vector

- missile event flags, defining the status of the missile, together with flags indicating termination cause.

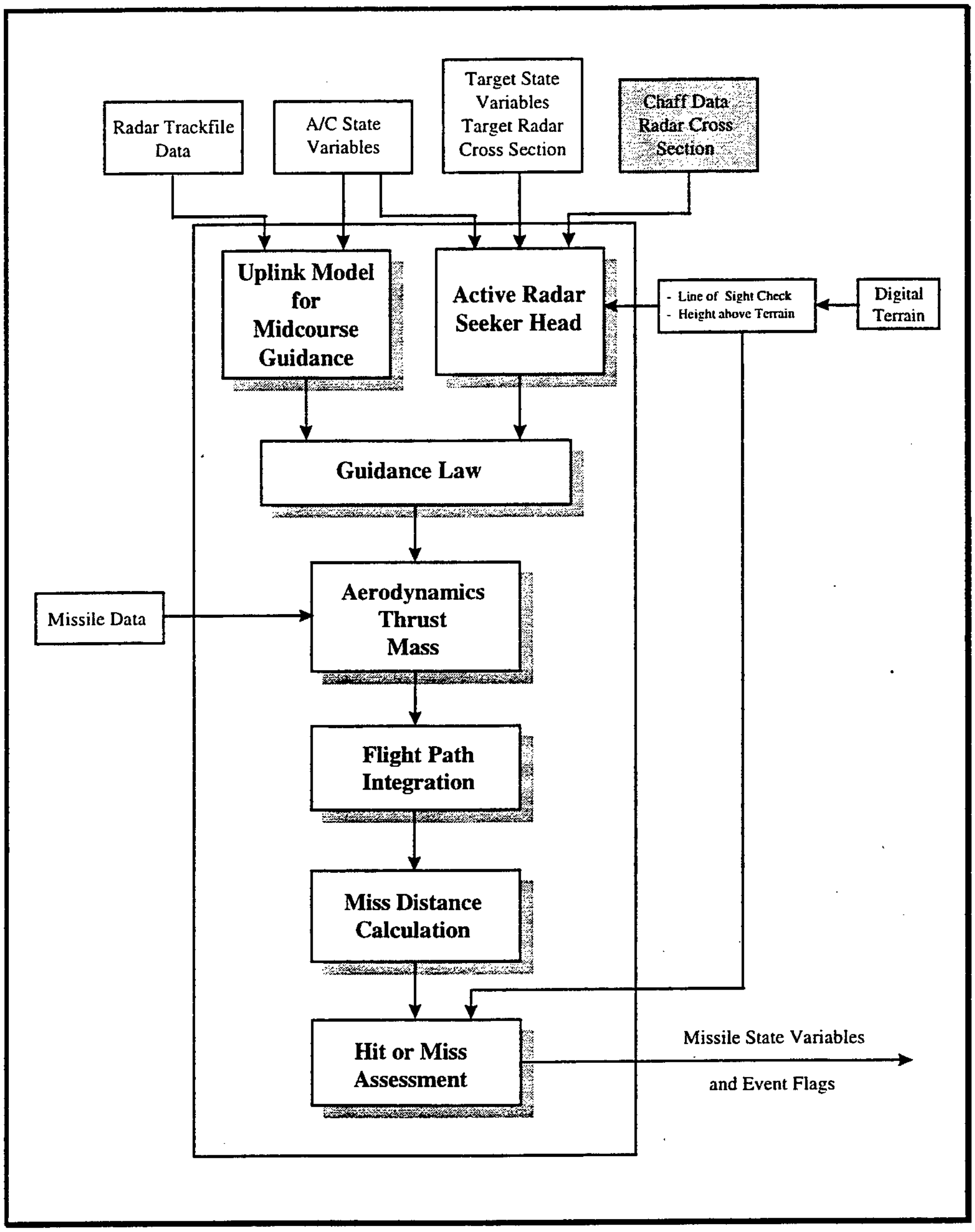


Fig. 3-24 Block Diagram of Medium Range Missile Model

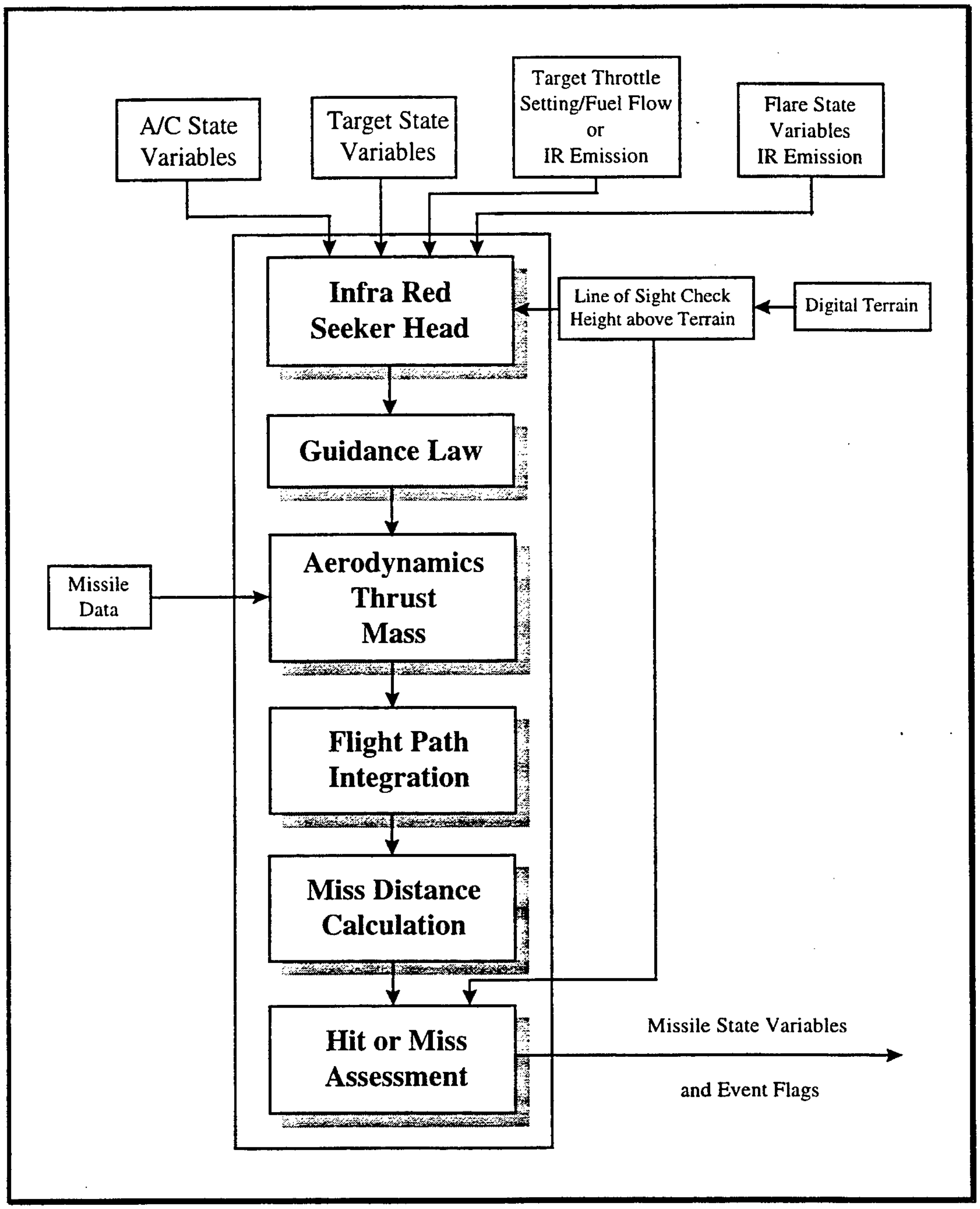


Fig. 3-25 Block Diagram of Short Range Missile Model

Main modules:

- Infra Red seeker head model
- guidance law
- aerodynamics, thrust and mass model
- flight path integration
- miss distance calculation
- hit or miss assessment.

3.2.2.2.3.3 Gun

Fig. 3-26 depicts the block diagram of the gun model.

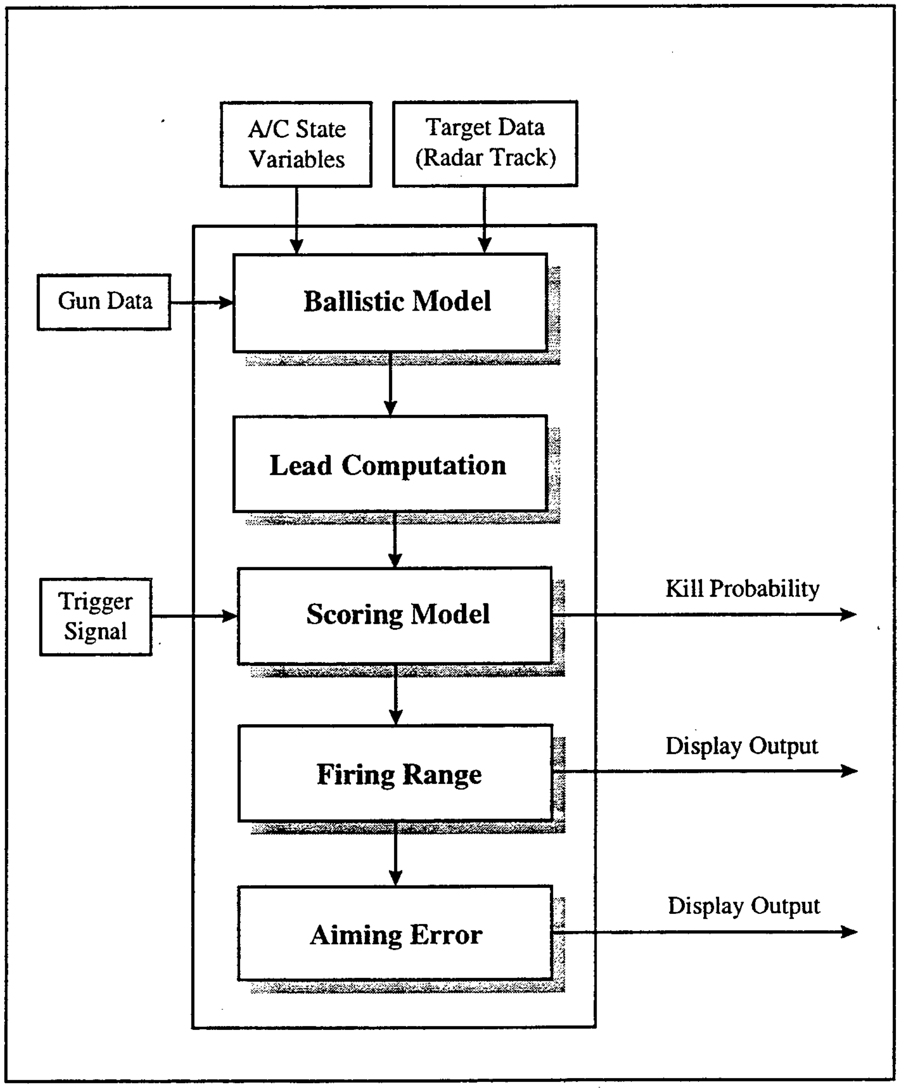


Fig. 3-26 Block Diagram of Gun Model

Input data:

- own aircraft state vector
- target state vector from the radar trackfile; "Single Target Track" mode of the radar is mandatory for lead computation.

Output data:

- kill probability of salvo
- cumulated kill probability for consecutive salvos.

With a suitable Ballistic Model and the measured target data, a Lead Computation is performed. Firing range and aiming error are displayed via the Head Up Display. When the trigger is pulled, a Scoring Model

is initiated. The Scoring Model computes hit probability followed by computation of kill probability using a Vulnerability Model of the target.

3.2.2.2.3.4 Flares

The block diagram of the flare model can be seen in Fig. 3-27.

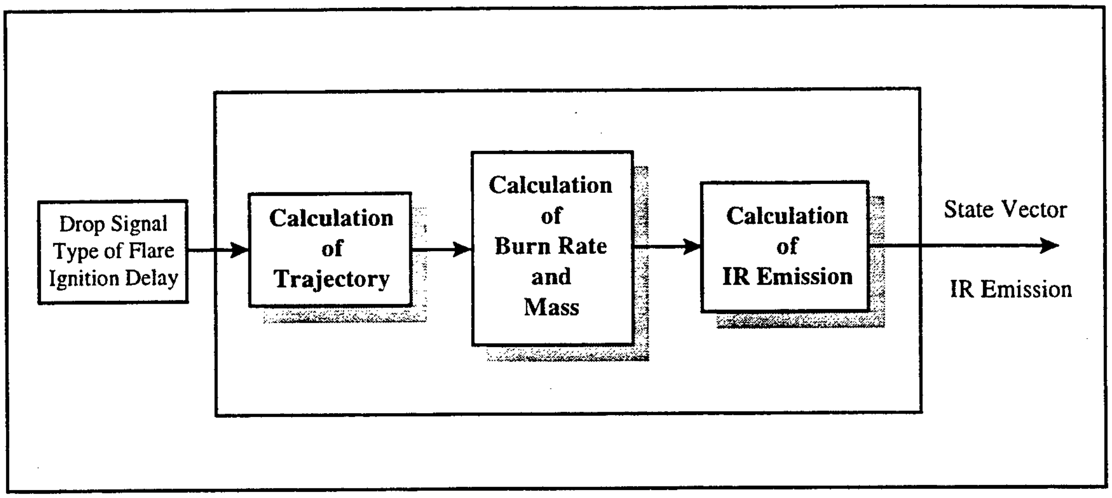


Fig. 3-27 Block Diagram of Flare Model

Input data:

- drop signal (actually the number of the aircraft dropping the flare)
- type of flare (model consists of a number of different flare types, characterized mainly by brightness over time)
- ignition delay (time that elapses until ignition of flare after deployment)
- random number for basic brightness (0.8 → 1.2).

Output data:

- flare state vector
- flare IR emission.

Main modules:

- calculation of trajectory
- calculation of burn rate and mass (where minimum mass controls termination of flare)
- calculation of IR emission

To save data transfer bandwidth, the flares are simulated at the side where the relevant missile is simulated. Each of the participants had the flare model within their simulation. Only the drop information of flares is transferred.

3.2.2.2.4 Displays and Controls for Combat Phase

The display layout for the combat phase is shown in Fig. 3-28. Four displays (3 HDD & HUD) are available.

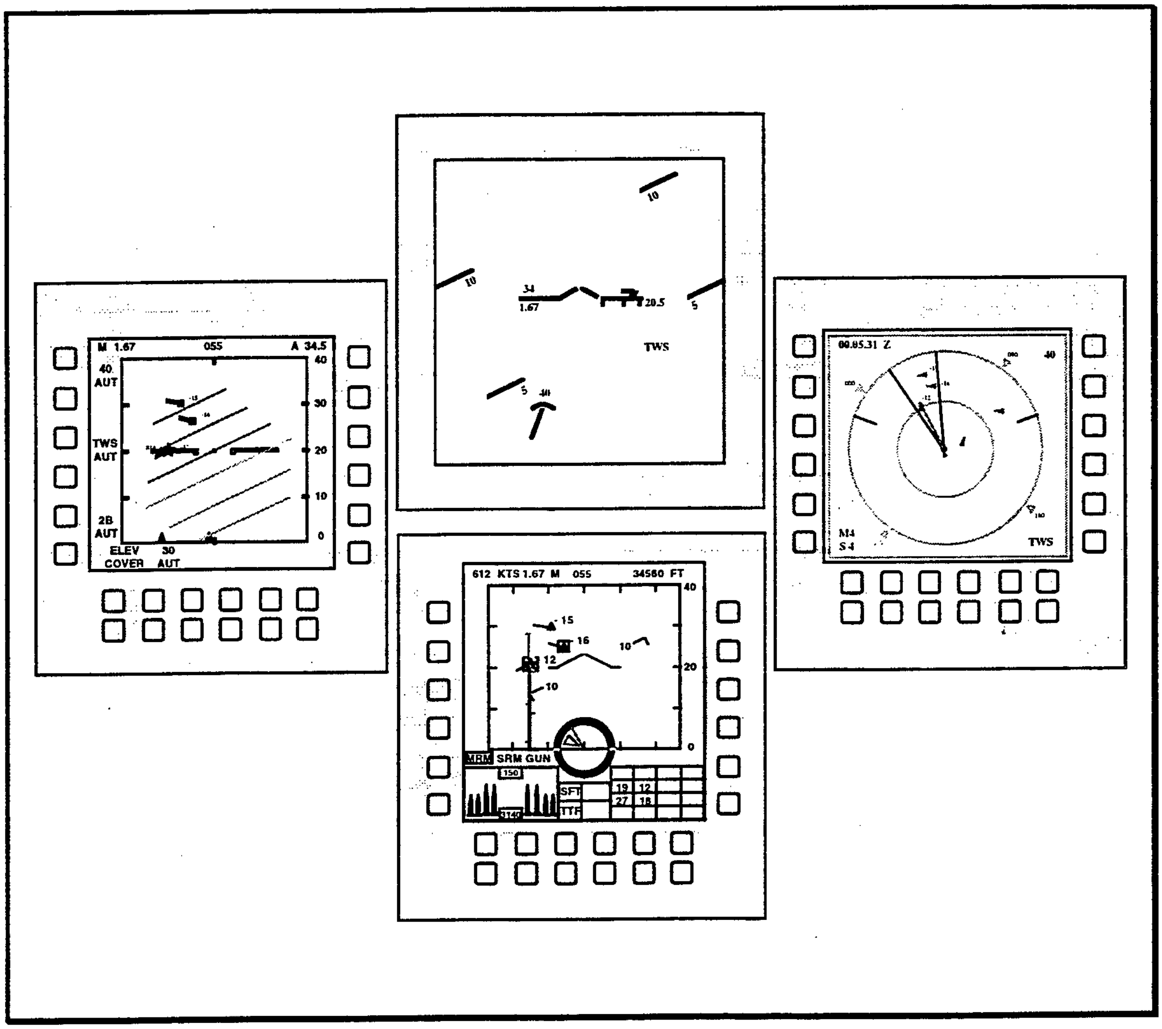


Fig. 3-28 Display Layout (Combat Phase)

These are:

- Radar Display
- Combat (or Tactical) Display
- Corporate Trackfile Indicator (CTI) (or Horizontal Situation) Display
- Head Up Display.

3.2.2.2.4.1 Radar Display

The display (Fig. 3-29) presents its target information in range versus azimuth (+ 70 to - 70 degrees).

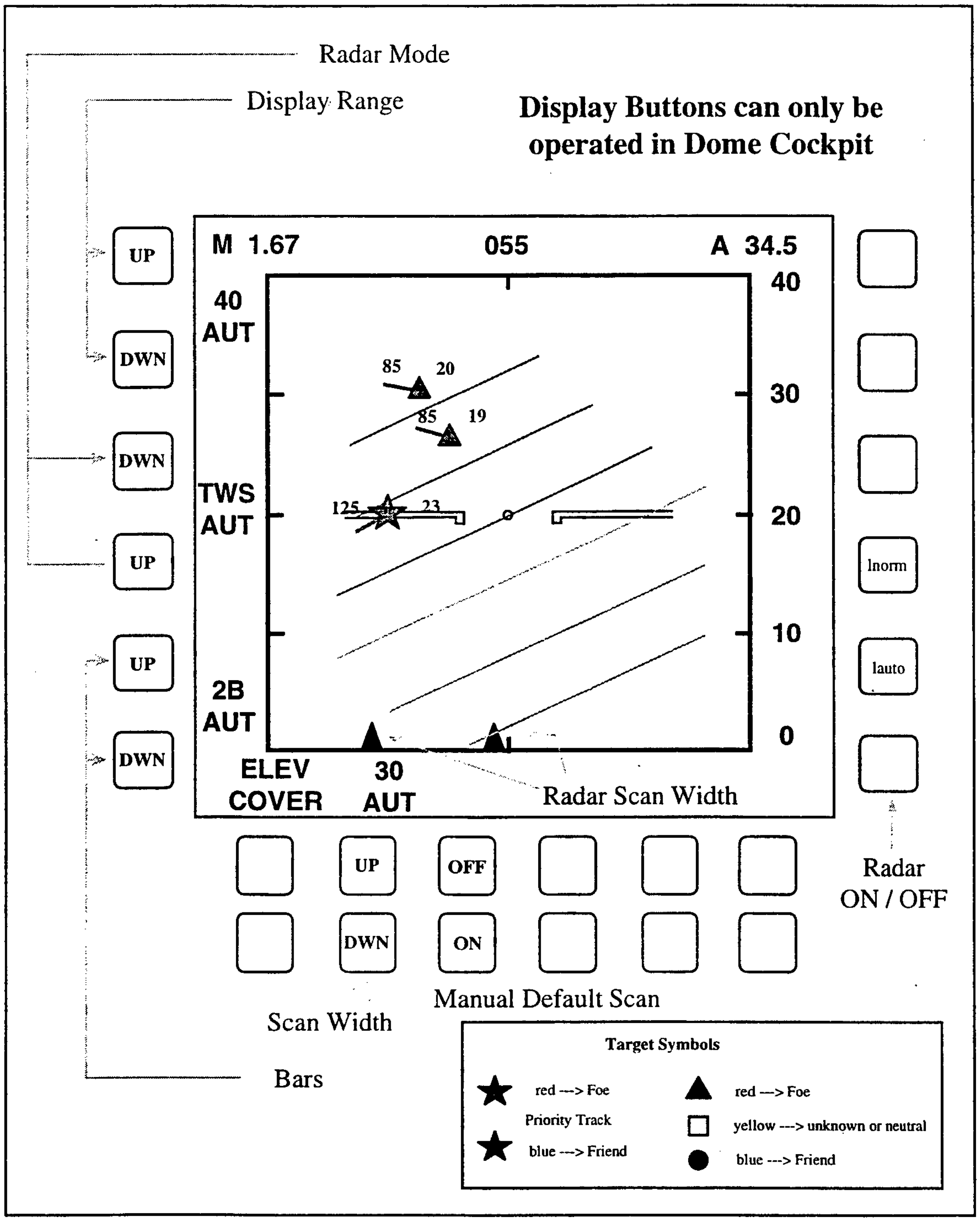


Fig. 3-29 Radar Display Symbology

It presents flight information such as

- Mach number (left upper corner)
- Heading (upper middle)
- Barometric Altitude (right upper corner)
- Pitch ladder (horizon line → green, sky → blue, earth → brown).

On the left side range scaling, radar mode and number of bars are presented. On the lower left side information about scan width is shown.

For definitions of azimuth coverage and elevation coverage of radar scan pattern see Fig. 3-37.

The notation of "AUT" below each of this information displays means that these parameters have been set automatically by the radar sensor management.

The present radar scan width and its horizontal position relative to the aircraft nose is shown by two triangles.

The target symbols used are shown in the insert below the radar display.

These symbols are:

- Red star --> Priority Track "Foe"
- Blue star --> Priority Track "Friend"
  (Prioritization algorithms will not prioritize friendly tracks; however, manual inputs, described later, can also prioritize friendly tracks)
- Red triangle --> tracks identified as "Foes"
- Yellow squares --> tracks "not yet identified" or "neutral"
- Blue circles --> tracks identified as "Friends".

The target symbols carry information, which are:

- on the left side Mach number (3 digits: e.g. 125 means Ma = 1.25) and
- on the right side target altitude (in 1000 ft units).

The radar will normally be off and can be switched on

- in the dome cockpit by the display button shown in Fig. 3-29;
- in the VLO-cockpit by button No. 7 on the control panel (see Fig. 3-44).

If the radar is switched on, a readout of radar altimeter is presented in the lower right corner.

NOTE: Display buttons in the VLO-cockpit are not operable

The display buttons in the dome cockpit allow manual changes to scan pattern parameters, radar mode and range scale setting.

This can be done by pushing the relevant "UP" or "DWN" button; e.g. pushing the "UP" button for bar setting would change the bar setting from 2 to 4 bars, the notation "AUT" would change into "MAN". The sensor management would then accept this as a manual input and would keep this bar setting from then on. The same is true for radar mode, scan width (azimuth coverage) or range scale setting.

Fig. 3-41 illustrates this as a "MANUAL OVERRIDE" to the sensor control.

A return to automatic mode can be done for

- individual settings, by pressing the "lauto" switch and the "UP" or "DWN" button of the desired parameter
- a complete return to automatic mode, by simply pressing the "lnorm" switch.

The following manual inputs to the sensor management can be made. These inputs are:

- Single Target Track (STT) on priority track.
  This can be done by pressing the "STT" button on the top of the throttle (see Fig. 3-42, "Throttle Controls").

NOTE: If a "Lock Break" occurs, the system will change to "SRA" (Short Range Acquisition) mode. If TWS is wanted, the STT button has to be pressed again. If left in SRA mode, the system will, if target is reacquired, return to STT.

- HUD Acquisition Mode (HUDAC)
  HUDAC mode can be selected, if the relevant button on the top of the throttle is pressed (Fig. 3-42). The HUDAC mode will be shown on the radar display by a blinking "HUDAC" insert (see Fig. 3-40).

  NOTE: The system will do STT on the first target acquired. The target can be rejected by the button on the top of the stick (see Fig. 3-43 Stick Controls). The system will then return to HUDAC mode. A return to automatic sensor management will happen, if the HUDAC button is pressed again.

  NOTE: If in HUDAC mode a friendly target is acquired, this target will automatically become the priority target and will be transferred to the combat display (a blue star in the radar display will notify the operator that this is a "friendly" target track).

- Manual Default Scan
  Should, by any reason, the "3 Scan Mode" be considered inappropriate (this scan mode is the normal search scan commanded by the Sensor Management, if there are no more tracks in the CTF or no priority track; an example for altitude coverage is shown in Fig. 3-37), a "Manual Default Scan" can be activated. An example of the altitude coverage can be seen in Fig. 3-38. This scan mode is visualized on the radar display by a blinking "MAN DEF" (see Fig. 3-39).
  This scan mode can be activated
  - in the dome cockpit by the relevant display buttons (Fig. 3-29);
  - in the VLO-cockpit by button No. 5 on the control panel (Fig. 3-44), ON / OFF function.

These inputs are illustrated as "MANUAL INPUTS" to the sensor management in Fig. 3-41.

3.2.2.2.4.2 Combat (Tactical) Display

As in the radar display, the combat display presents its target information in azimuth versus range.

In Fig. 3-30, the same situation regarding targets as in the radar display is shown.

The combat display has no pitch ladder, only bank angle is presented via a roll marker. Pitch attitude information is given by a digital readout close to the roll marker (in 10 degrees units).

The priority target is denoted by a red star, the secondary targets are shown as red triangles. Target altitude (1000 ft units) is written on the right side of each target symbol with Mach number on the left side, similar to the radar display.

The present software status allows the display of up to 4 "Lock On" target tracks. These tracks are selected by a prioritization algorithm which determines the

- priority target track and
- up to 3 next ranking target tracks.

NOTE: As long as "aggressive" tracks (i.e. radar tracks with associated RWR-tracks or active RWR-tracks) are present, these tracks are of higher priority than "nonaggressive" tracks.

"Lock On" tracks are those tracks, where the full target state is known, i.e. position and velocity vector.

Tracks identified as friendly are not processed by the prioritization algorithm and will therefore not appear in the combat display. This will prevent unintentional firings on own forces. However, using manual inputs, which will be discussed later, tracks identified as own forces can be transferred to the combat display.

Manual Prioritization:

Priority can be changed via manual input. This is done via the button on the top of the throttle (see Fig. 3-42).

By pressing this button the automatic prioritization algorithm will be interrupted and replaced by the manual mode. Any "Lock On" radar track or active RWR track in the "Corporate Track File" (CTF; a trackfile combining the information of the individual sensor trackfiles - Radar and RWR) can be selected by stepping from one eligible track to the next by pressing the button. This can best be observed on the third Head Down Display (CTI Display, which will be described next). This display contains all tracks (radar tracks - active or extrapolating and RWR tracks - active or extrapolating).

NOTE: With this manual input also tracks of own force can be prioritized and thereby transferred to the combat display.

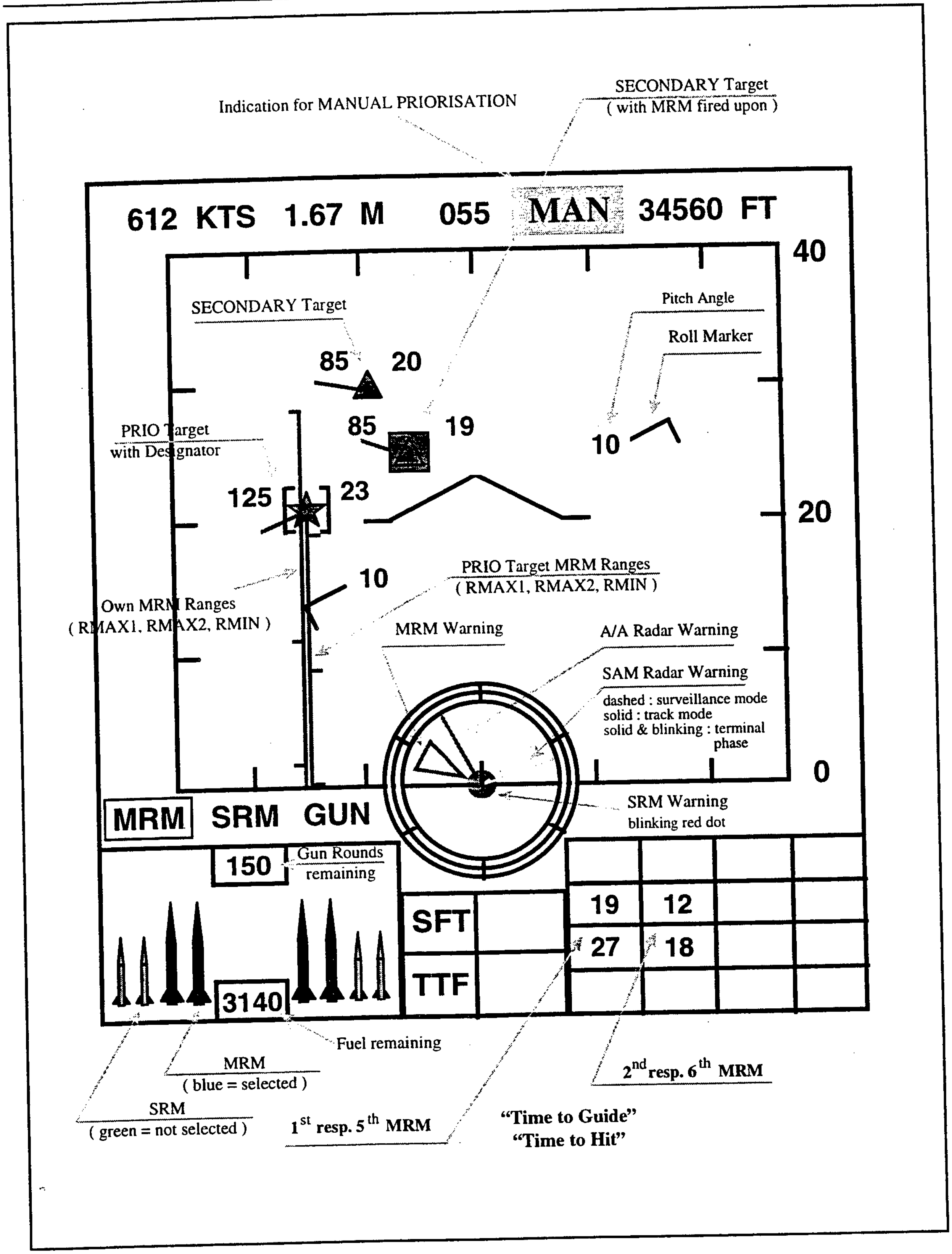


Fig. 3-30 Combat Display Symbology (MRM selected)

In the Manual Prioritization Mode only the priority target track is selected, the algorithm for secondary tracks will be still effective.

The Manual Prioritization Mode is shown on the combat display by the insert "MAN" on the upper right side.

This manual mode can be reset by a button on the top of the stick (see Fig. 3-43 Stick Controls).

Target Reject:

It is also possible to reject the present priority target track via a button on the stick top

The rejected tracks get a "reject flag" and will no longer be processed in the prioritization algorithms. If Manual Prioritization is selected, these flags are canceled and after an eventual return to Automatic Prioritization, these tracks will again be processed.

> *NOTE: The radar scan will normally be centered on the priority track. If the priority track is outside of the radar gimbal limit, it will be parked at the edge of the gimbal limit. To center the radar scan to any other than the present priority track, use "Manual Prioritization" or "Target Reject".*

Fig. 3-41 illustrates these actions as "MANUAL INPUTS" to Prioritization Algorithms.

For the priority target, own missile ranges are shown. These ranges are presented in blue.

Also, the missile ranges of the priority target against own aircraft are presented (assumption is, that target has the same missile type as own ship). These ranges are shown in red.

Three missile range indications are displayed for MRM. These are:

- RMAX1 missile range,
  if target continues with present heading and speed then performs a 3g turn away when missile range to target is less than 1 nautical mile.
- RMAX2 missile range,
  if target continues with present heading and speed then performs a 6g turn away when missile range to target is less than 10 km.
- RMIN Minimum missile range

Inrange calculations are only performed and missile ranges displayed if radar has "Lock On" to target.

Two missile range informations are displayed for SRM. These are:

- RMAX missile range, if target starts a 3g turn away at missile firing time
- RMIN Minimum missile range

Own inrange calculations for SRM are only performed and missile ranges displayed if two conditions are fulfilled:

- radar "Lock On" to target
- IR seeker head of to be fired missile has "Target Lock".

Target Designator:

The priority target track normally carries the target designator (white brackets). The target designator can be stepped to each target track on the combat display by the button on the throttle top (see Fig. 3-42).

The target track carrying the designator brackets will be that target the missile will be fired at (MRM or SRM). If a secondary target track has been designated and fired upon, the designator will automatically return to the priority target track.

If a MRM has been fired on a secondary target track, a red square is added to the relevant target symbol.

Weapons Display:

The lower left side of the display shows a weapons display with information about the selected weapon and weapons remaining.

Weapons Selection:

Weapon selection can be made via a three way switch on the stick top (see Fig. 3-43 Stick Controls).

Pressing the switch forward will select MRM, pressing it backwards will select SRM, pressing this switch down will select gun.

The selection of weapons is shown on the combat display in two ways:

- White box on top of weapons display shows selected weapon;
- Color code will show selected missile
  green : not selected
  blue : selected.
- Display of gun rounds will change background color into blue and numbers to white, if gun is selected.

After missile triggering, the activated missile will turn to red until it leaves the launcher. If missile launch conditions are not fulfilled the missile will return to its former blue color.

The time between "Trigger" and "Launch" is 1.0 sec (Launch delay time).

There is a minimum time of 1.5 sec between consecutive missile firings.

Permanent squeezing of the missile trigger will not cause further missile launches.

On the lower right side information about fired missiles is shown. This information is:

- TIME TO CONTROL
  approximate time until missile seeker head will have acquired the target with own radar seeker head and be autonomous. Before that missile is in midcourse guidance phase, target has to be tracked to give updates to missile.
- TIME TO HIT
  approximate time until missile will hit the target. If no "Time Hit" is shown, it indicates that fired missile will probably not reach the target.

These times are approximations only, which are calculated with range to target at firing time and approximations of missile closing speed versus time of missile flight.

> *NOTE*
> *For MRM no shootlights will be displayed. Decision to fire completely up to the pilot.*
> *For SRM shootlights are displayed as soon as target is insideRMAX and IR seeker head has "Lock" on target.*

The weapons display also contains information about remaining fuel (in kg). Background of fuel indication will turn blue if "BINGO" fuel is reached (600 kg); and red if "RTB" fuel is reached (400 kg).

RWR Display:

Finally, a RWR display is integrated into the combat display, where the contents of the RWR trackfile, the surface to air missile (SAM) radar warnings, the MRM warnings and the SRM IR warnings are presented.

The symbology for this information is:

- Red strobes :
  Indication of A/A radar warnings in the horizontal plane
- Yellow strobes :
  Indication of SAM radar warnings
- Red triangle :
  Indication of MRM warnings displaying the direction of the missile in the horizontal plane
- Red dot :
  Indication of SRM IR warnings.

NOTE: There is no Surface to Air Missile threat in TRACE

3.2.2.2.4.3 CTI - Display

The CTI display (Fig. 3-31) presents target track information in a "bird's eye view". Own aircraft is in the center of the display (circle with cross).

Also, as an example, the target situation is the same as in the previous displays.

This display presents the complete contents of the "Corporate Trackfile". This also includes extrapolating target tracks and RWR information.

Target symbols used are:

- Red triangles :
  "foes", filled triangles are "Lock On" radar tracks open triangles are extrapolating radar tracks
- Blue triangles:
  "friends", filled triangles are "Lock On" radar tracks open triangles are extrapolating radar tracks

The orientation of the triangles show target heading. Altitude difference is displayed similar to radar and combat displays.

The priority target track is indicated by a blue "thomb". In this example the priority track is associated with a RWR track which is indicated by the red line to the priority track.

Position of present radar scan is presented and corresponds to the green triangles in the radar display. Radar gimbal limits are also indicated.

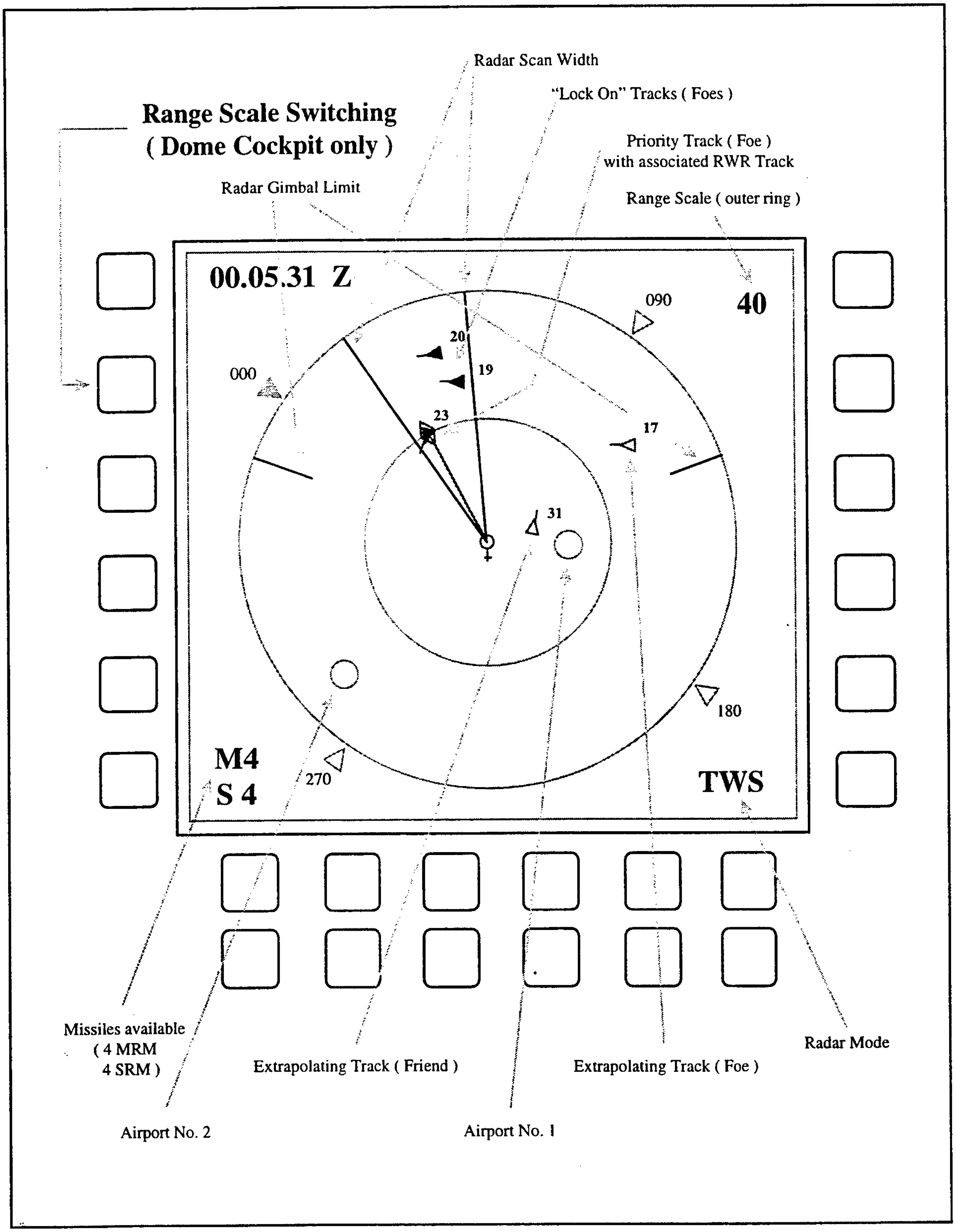


Fig. 3-31 CTI Display Symbology

As additional information, heading markers are on the outer ring. Position of Airport No. 1 and Airport No. 2 is denoted by green circles.

A digital readout for the range scale of the outer ring is shown in the upper right corner. This range scale setting is 80 nautical miles by default, it can be changed manually by:

- the display button in the dome cockpit;
- the switch on the throttle top (see Fig. 3-31) in the VLO-cockpit.

In the lower right corner the present radar mode is shown.

Information about missiles remaining is given in the lower left corner (M = MRM, S = SRM).

In the left upper corner, a time readout is displayed starting with 00.00.00 when the CTI display is activated (if deactivated, this time readout will be reset to zero again).

3.2.2.2.4.4 Head Up Display

3.2.2.2.4.4.1 Head Up Display Symbologies

Head Up display symbology will change depending upon the weapon selected. Symbology elements have been held to a minimum for as little clutter as possible.

3.2.2.2.4.4.2 HUD Symbology for MRM Selection

This symbology is shown in Fig. 3-32; target situation is again the same as presented in HDD's.

In the center of the HUD, the own aircraft symbol is positioned. On its left side, altitude (in 1000 ft units AGL - Above Ground Level - indication; over 6600 ft AGL, barometric altitude will be displayed) is displayed. Below that, Mach number is presented (if below "Corner Speed", Indicated Airspeed will be displayed).

On the right side, the own missile ranges are depicted (with RMAX1, RMAX2 and RMIN representation), together with target symbol and the indication of closing speed and a digital readout of range to target (in nautical miles).

Spatial direction of MRM warning is shown underneath own aircraft symbol.

In the upper left corner of the display an indication of g-load is presented.

Spatial direction to target is represented by the target designator symbol; a line points to the target which is outside the HUD FOV. Spatial angle to target is shown above target designator (in 10 degrees units). The Target designator will change from a semicircle to a square, if Manual Prioritization is selected.

Pitch ladder and radar mode complete the HUD symbology.

3.2.2.2.4.4.3 HUD Symbology for SRM Selection

The symbology is essentially the same, except that the IR seeker head FOV of the SRM is scaled down to fit the HUD FOV and also the position of the target designator symbol is scaled to the IR seeker head FOV (Fig. 3-33).

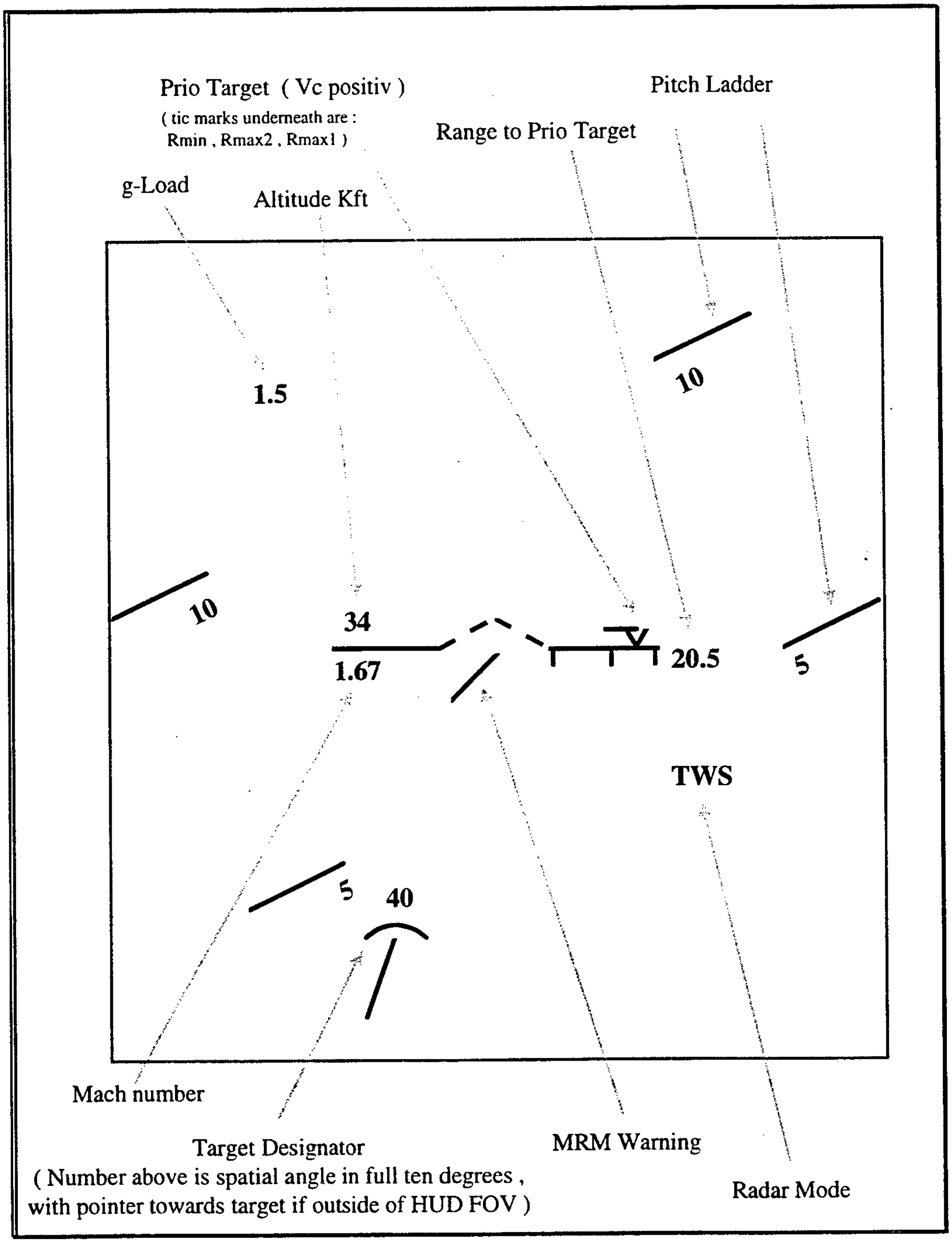


Fig. 3-32 HUD Combat Format (MRM selected)

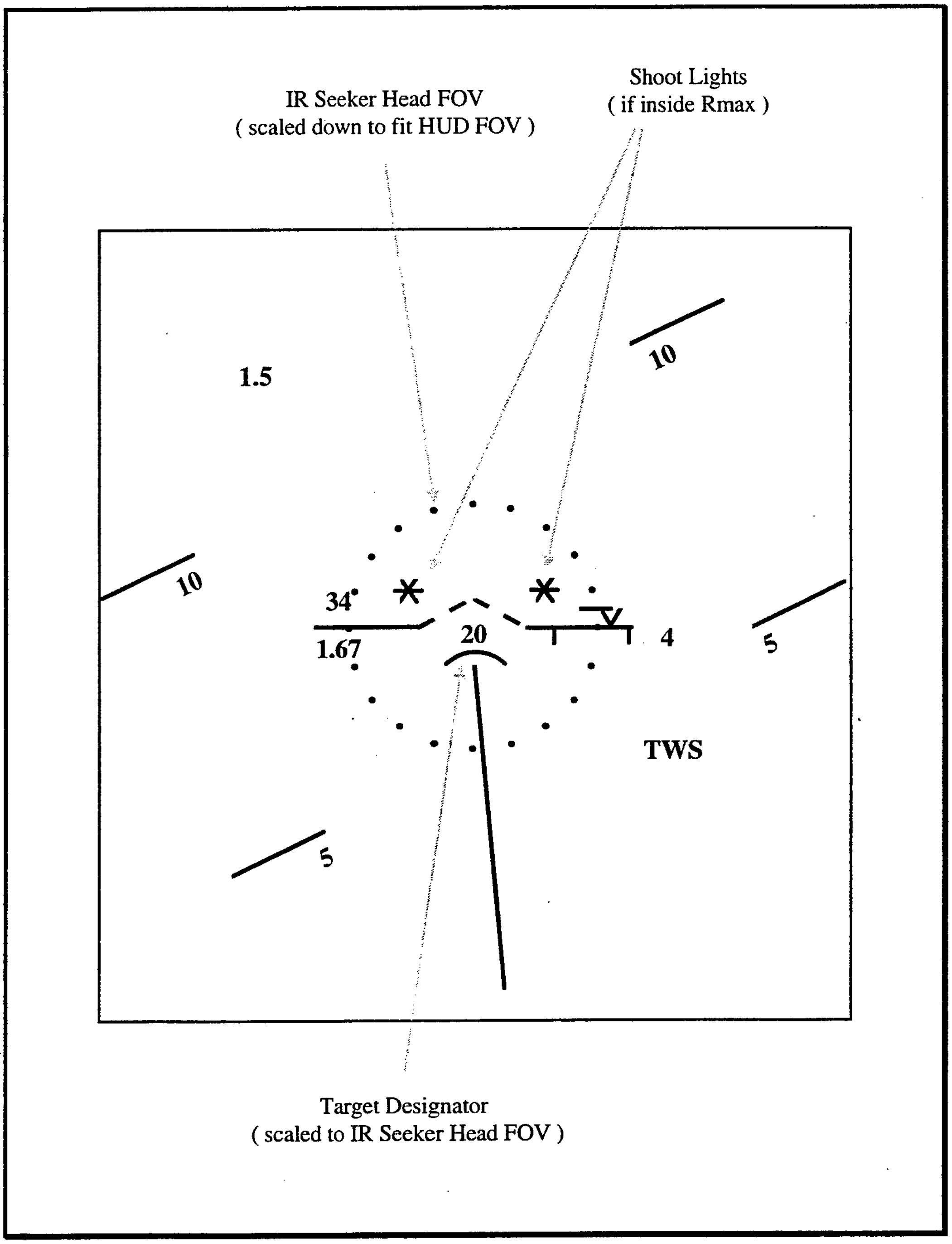


Fig. 3-33 HUD Combat Format (SRM selected)

3.2.2.2.4.4.4 HUD Symbology for Gun Selection

The HUD shows a firing condition; gun pipper and target designator symbol are aligned, target is within maximum and minimum gun range, STT is selected (which is the prerequisite for gun lead computation) and shootlights are shown (Fig. 3-34).

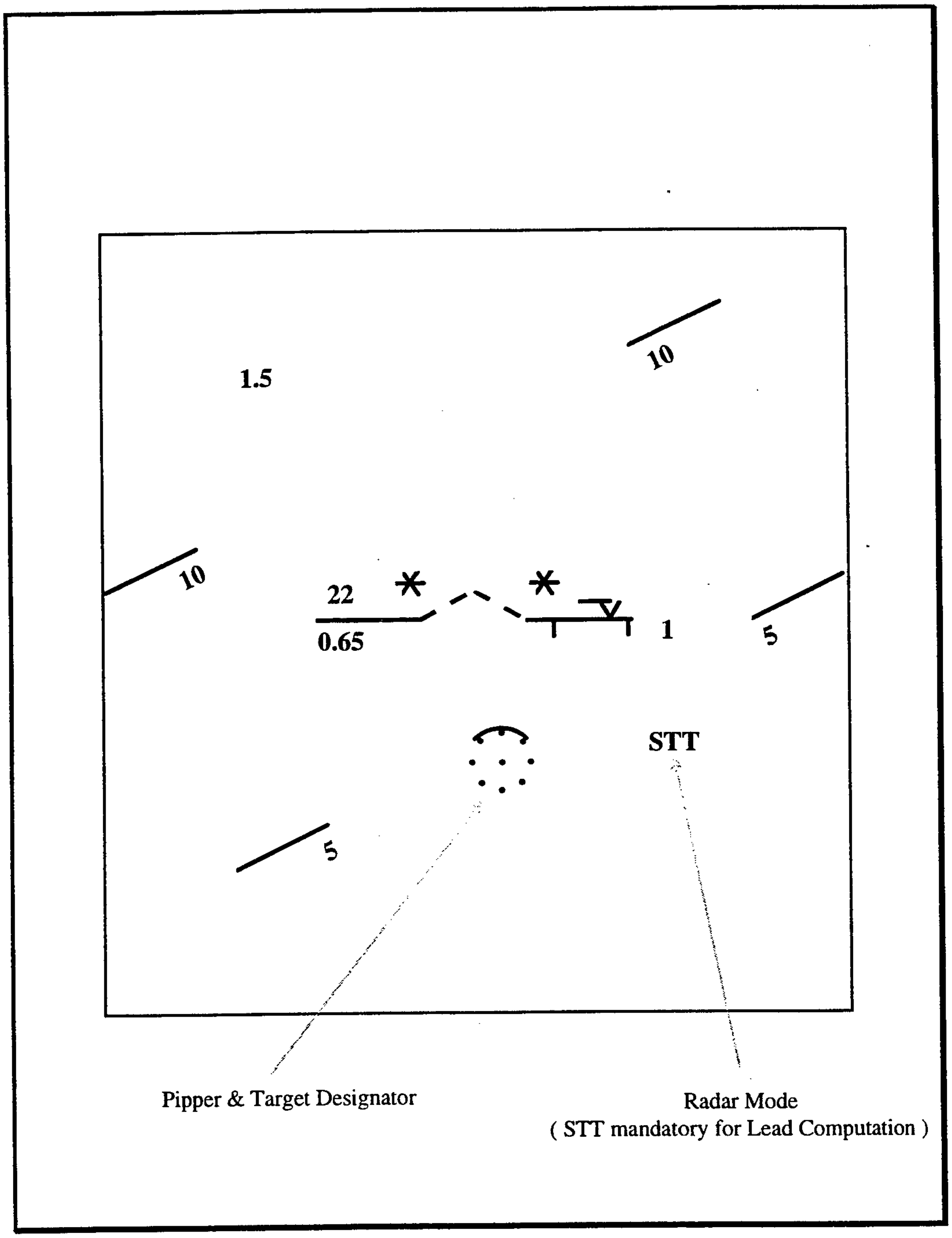


Fig. 3-34 HUD Combat Format (GUN selected)

3.2.2.2.4.4.5 HUD Symbology for Navigation Mode

For the sake of completeness the navigation format is also described (Fig. 3-35).

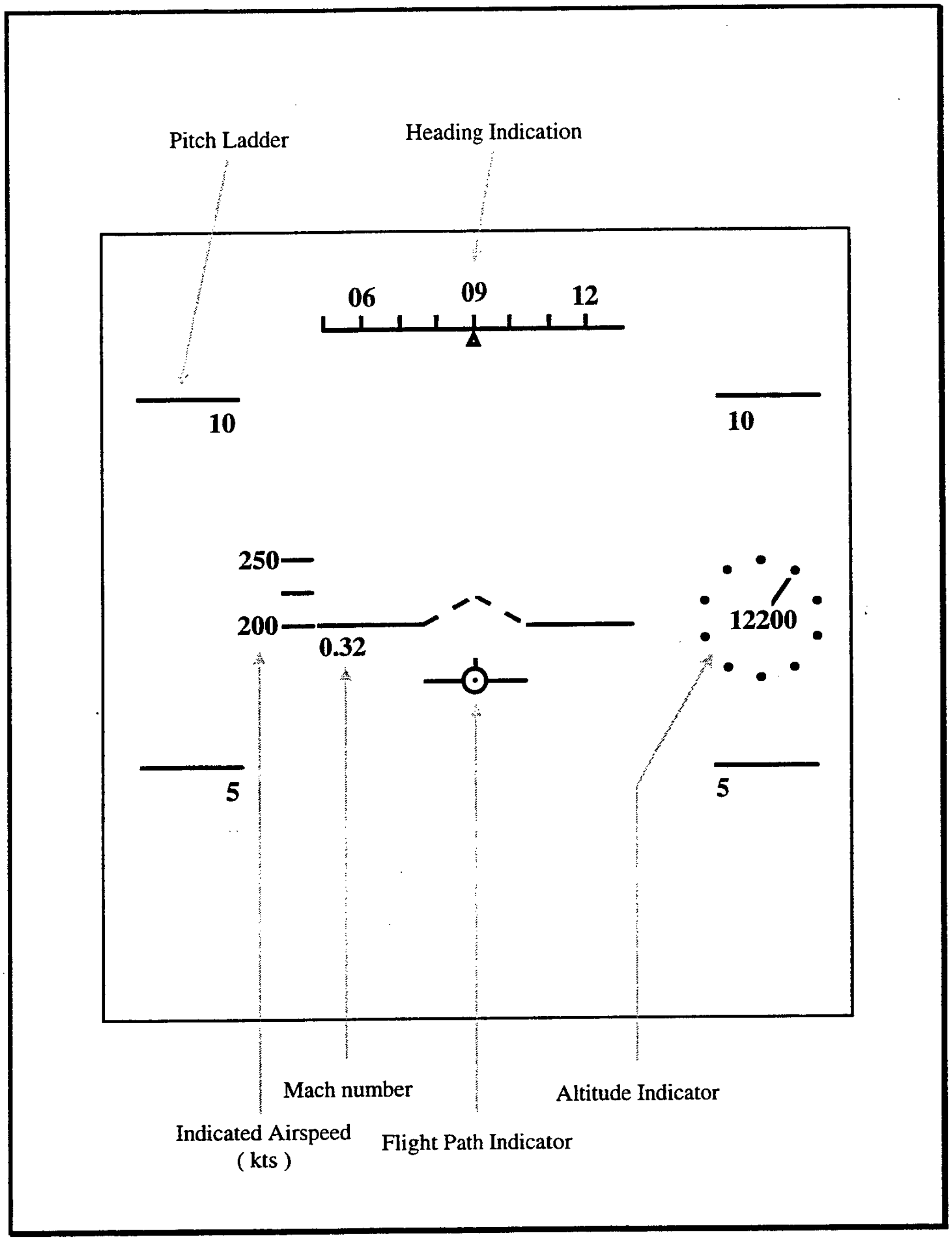


Fig. 3-35 HUD Navigation Format

This format has a heading indication at the top. The altitude indicator (AGL, resp. Barometric altitude if over 6600 ft AGL) is on the right side.

Mach number readout is shown on the left side together with a Indicated Airspeed band (in kts).

Pitch ladder and flight path indicators complete the navigation format.

NOTE: HUD Navigation Mode is not available in VLO-Cockpit

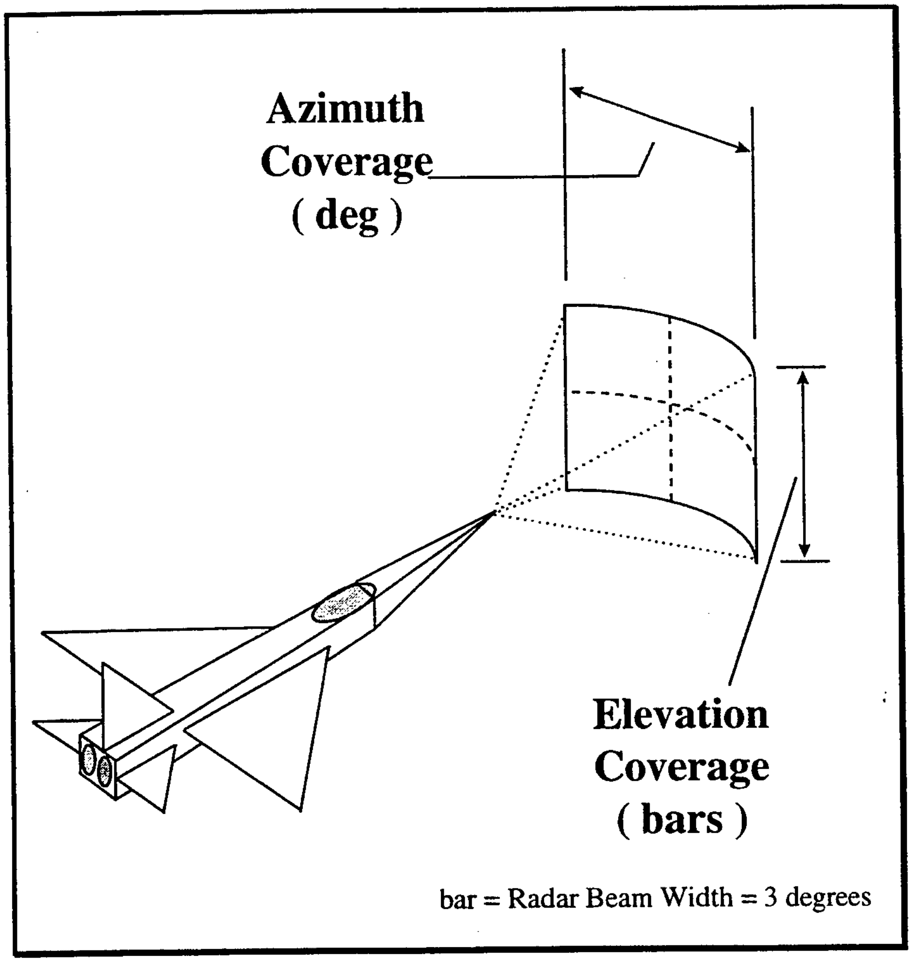


Fig. 3-36 Radar Scan Pattern

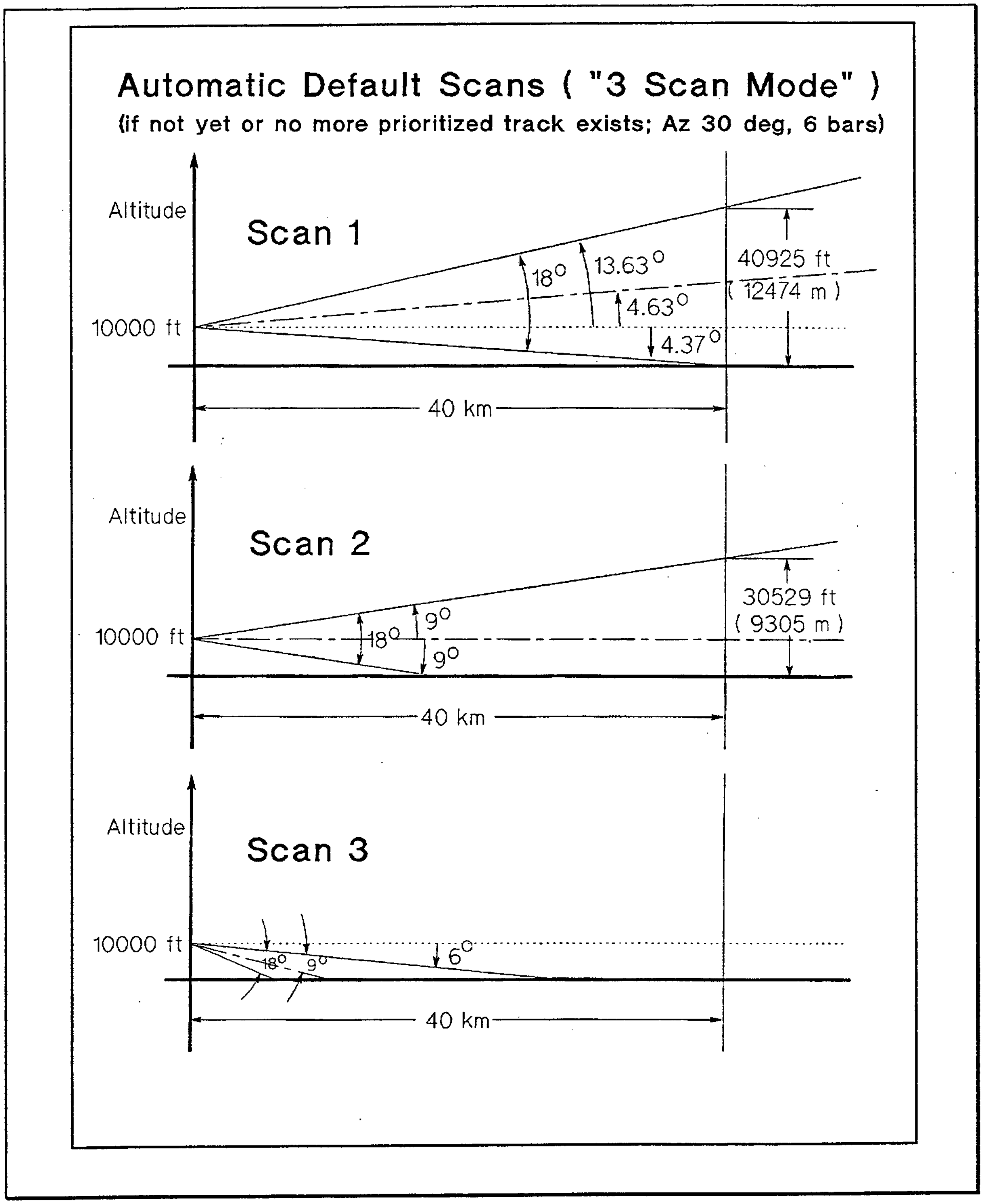
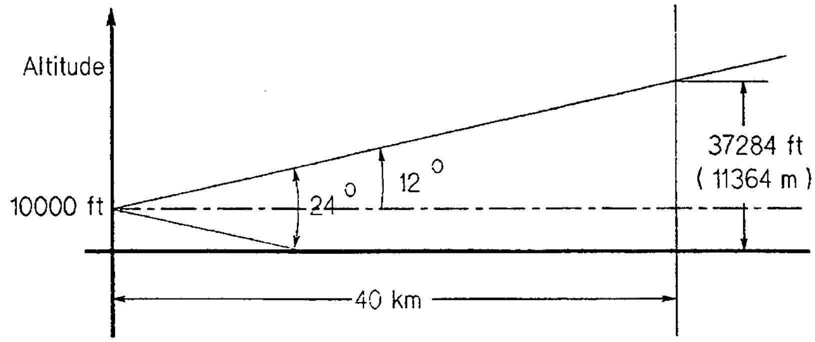


Fig. 3-37 Example of Altitude Coverage of "3 Scan Mode

Manual Default Scan

(Az 45 deg , 8 bars ;
activated by relevant Radar Display buttons)



HUDAQ - MODE (30 deg , 8 bars)

Activation by button on throttle
at target detection --> switch to STT
(first target that is detected)

SINGLE TARGET TRACK (STT)

Activation by button on throttle
priority track (radar track) must exist

Fig. 3-38 Example of Altitude Coverage of Manual Default Scan

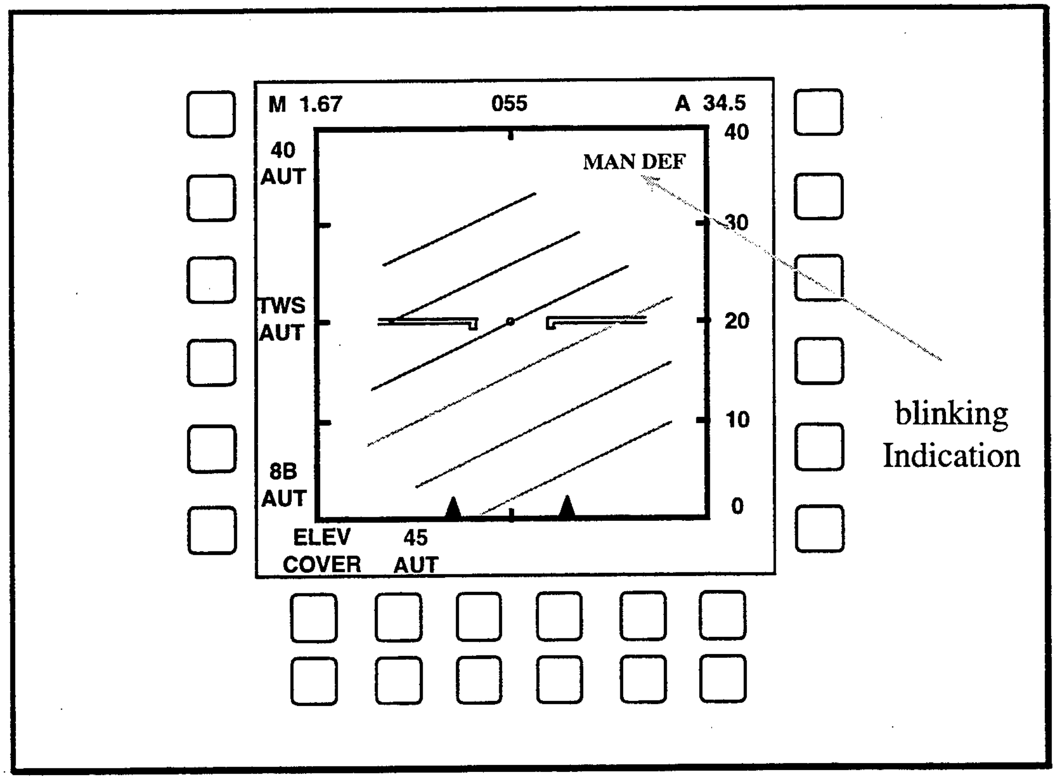


Fig. 3-39 Indication for Manual Default Scan

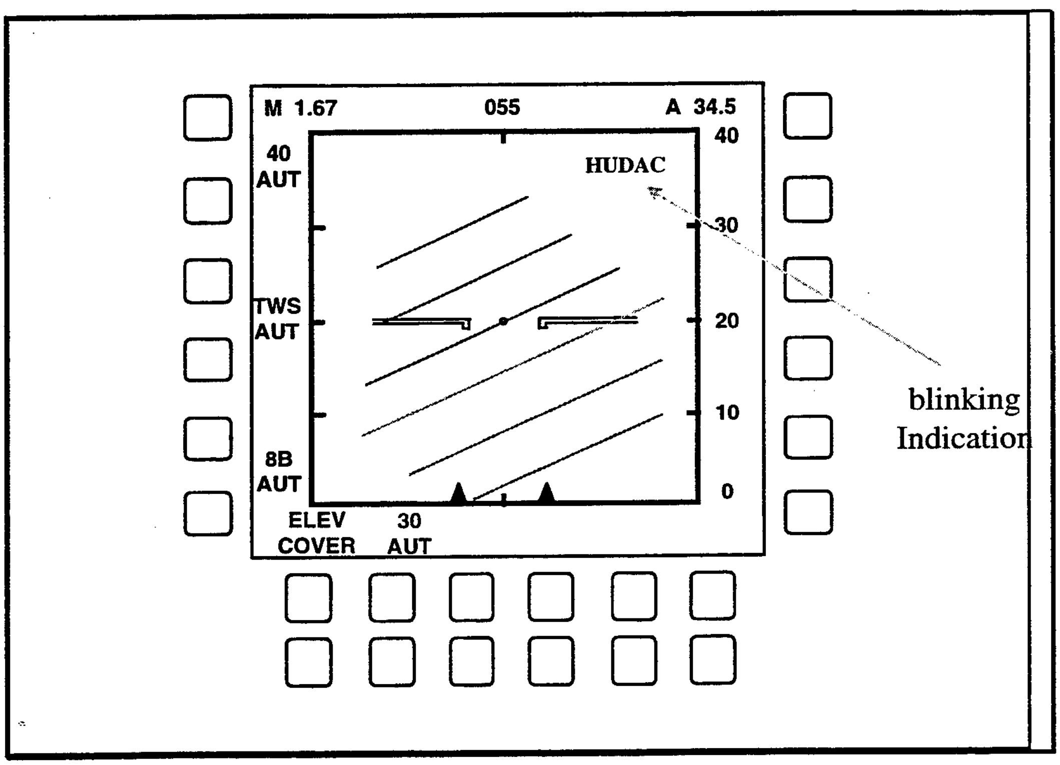


Fig. 3-40 Indication for HUD Acquisition Mode

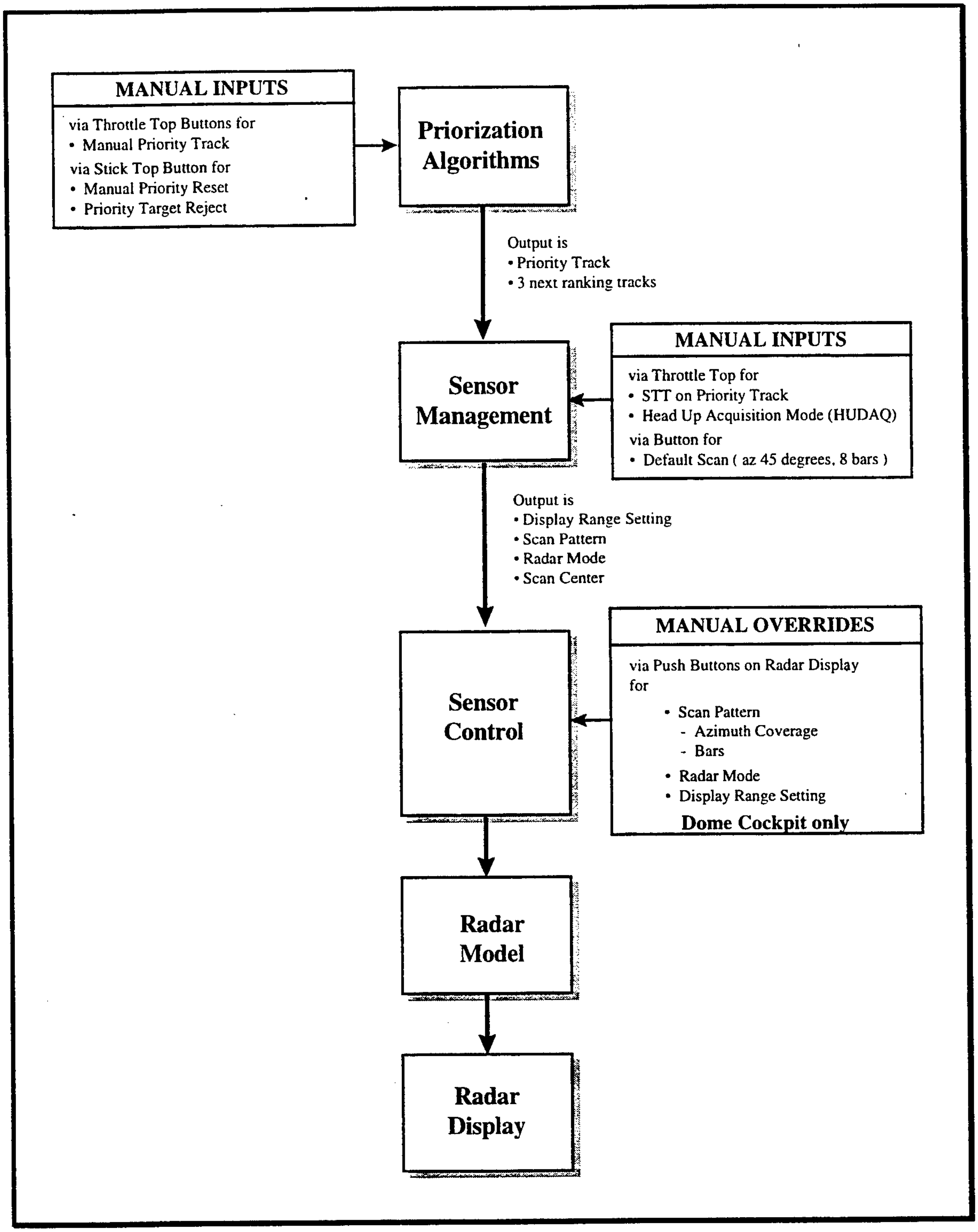


Fig. 3-41 Manual Inputs and Overrides

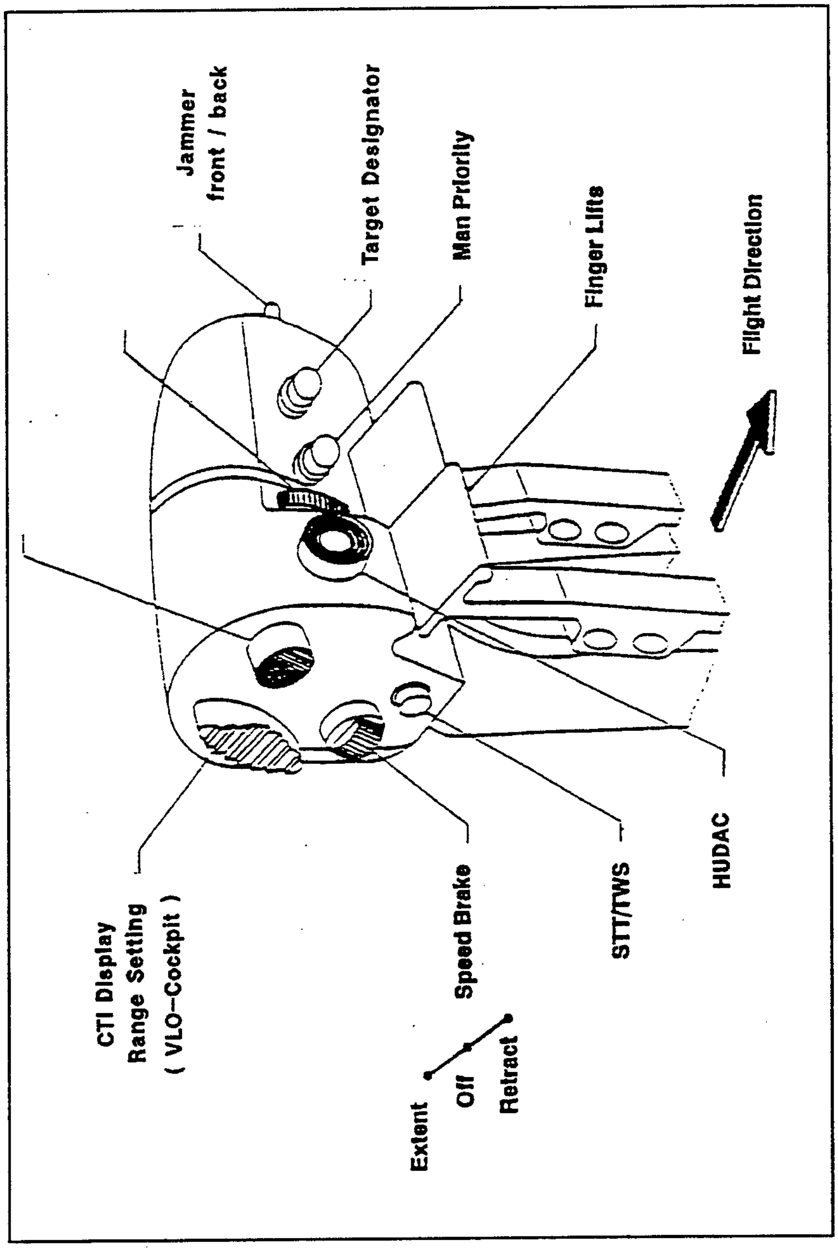


Fig. 3-42 Throttle Controls

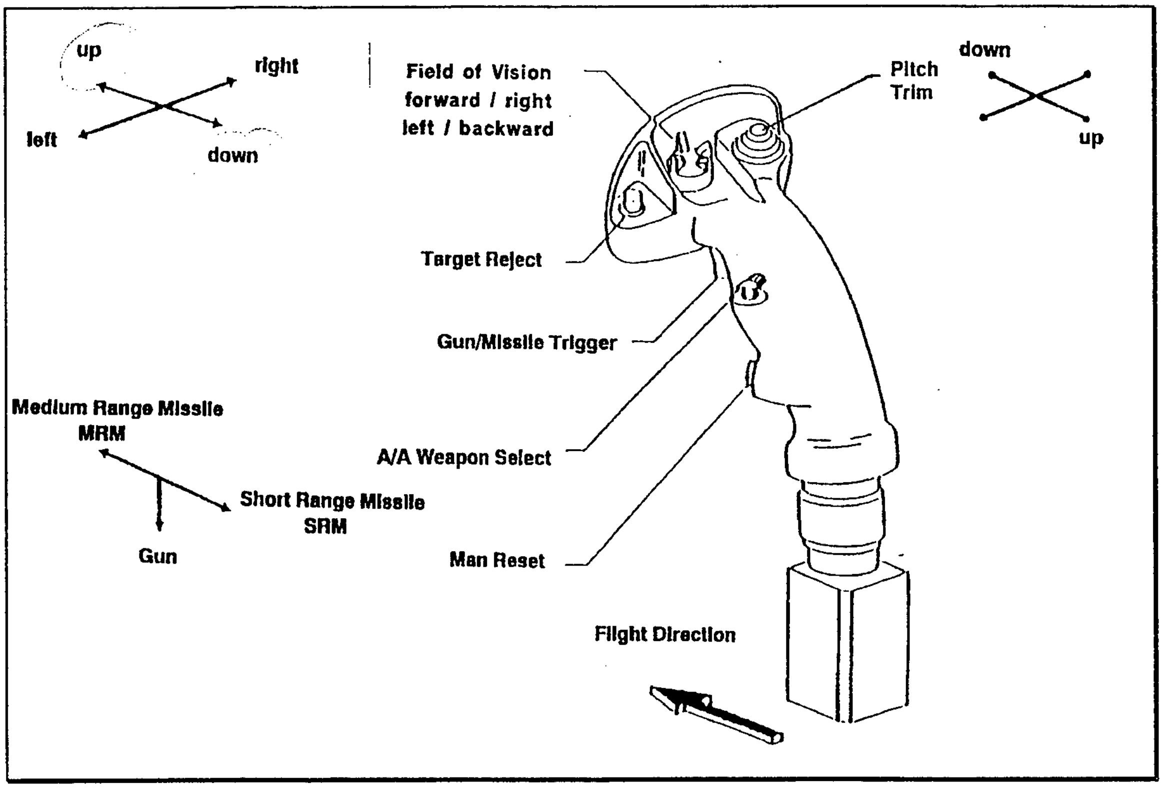


Fig. 3-43 Stick Controls

1 ADI TAC	2 SYSTEM ITAC MAP	3 MAP ZOOM	INIT
4 Jammer	5 Default Scan	6	RUN
7 Radar ON/OFF	8 Deactivate Groundcrash	9	HOLD
10	11 Deactivate Hit-Crash	12 Fuel	
13 END	14	15 Eyepoint MM	END

Fig. 3-44 Control Panel of VLO-Cockpit

3.2.2.2.5 Deployment of Expendables

Expendables on board the aircraft are:

- Flares against SRM
- Chaff against MRM

NOTE: Chaff is not available in the TRACE project

All expendables are dropped automatically by the system.

Flares will be dropped as soon as the IR missile warning is activated.
Number and sequence of flares dropped depends on:

- missile in forward or backward hemisphere
- present throttle position
- approximate range of missile to aircraft.

At present, a maximum of 8 flares will be dropped against each missile.

NOTE: Best results are achieved, if flare drop is accompanied by an avoidance maneuver and decrease of throttle setting.

3.2.2.2.6 Flight Envelope

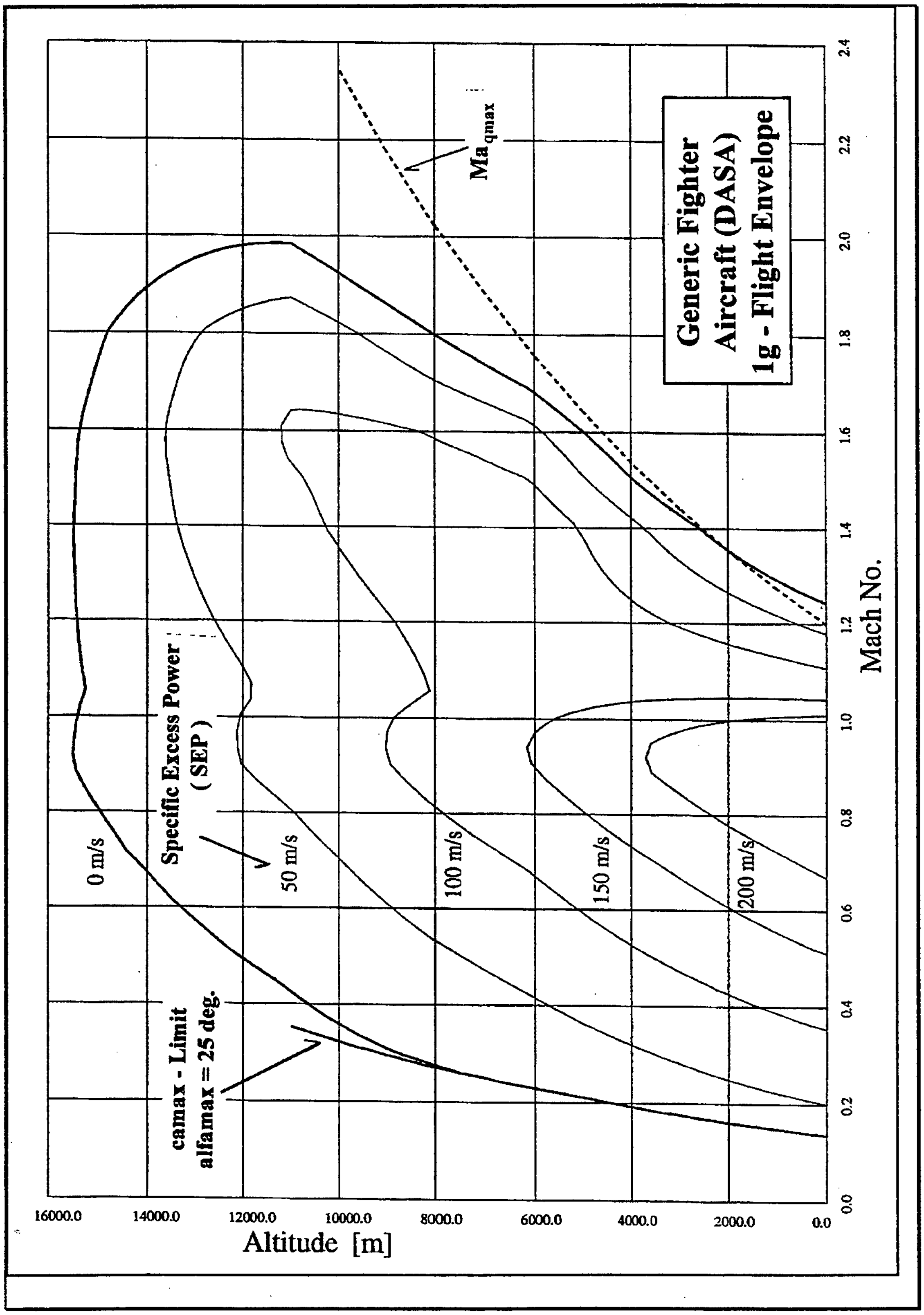


Fig. 3-45 Flight Envelope (1g - Flight)

3.2.3 Network Interface Computer (NIC)

3.2.3.1 DASA NIC

The Dasa NIC Computer at AFRL is comprised of a Force VMEbus rack connected via SCRAMNet to the AFRL Simulators and connected via Ethernet to the WAN interface, an Ascend Pipeline 50 ISDN router (2 B-channels, total bandwidth 128 kbit/s). A block diagram of the NIC configuration at AFRL is shown in Fig. 3-46.

The Dasa NIC Computer in Munich uses a Force Sparc CPU from the VLO cockpit simulator which is also connected via SCRAMNet to the VLO cockpit simulator, the Dome cockpit simulator and the CGF simulator. A block diagram of the NIC configuration at DASA Ottobrunn is shown in Fig. 3-47.

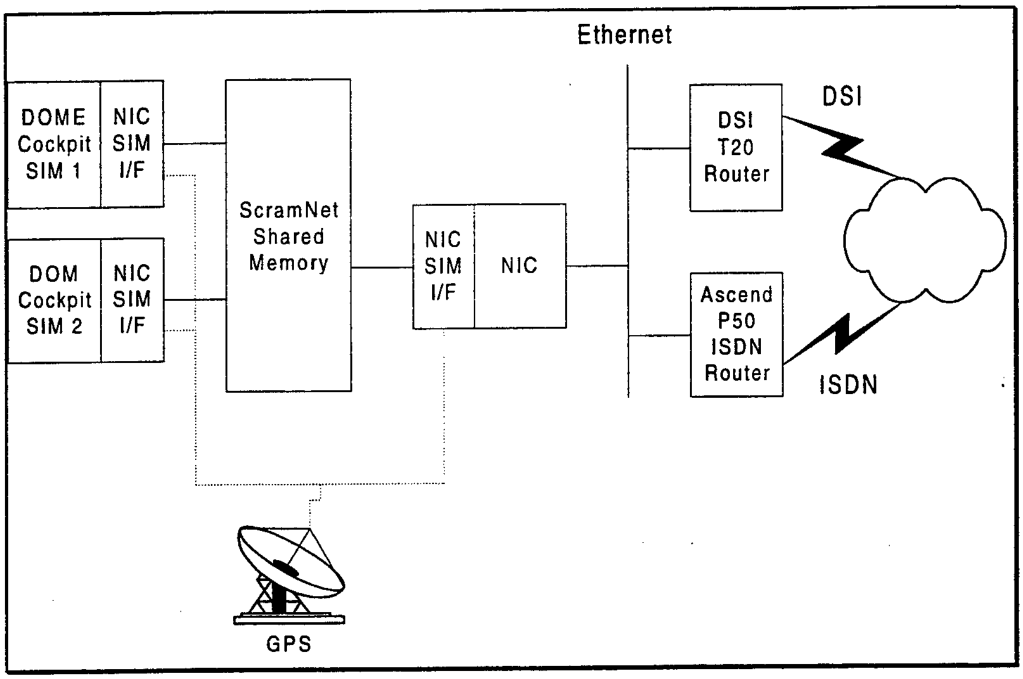


Fig. 3-46 DASA NIC Computer configuration at AFRL

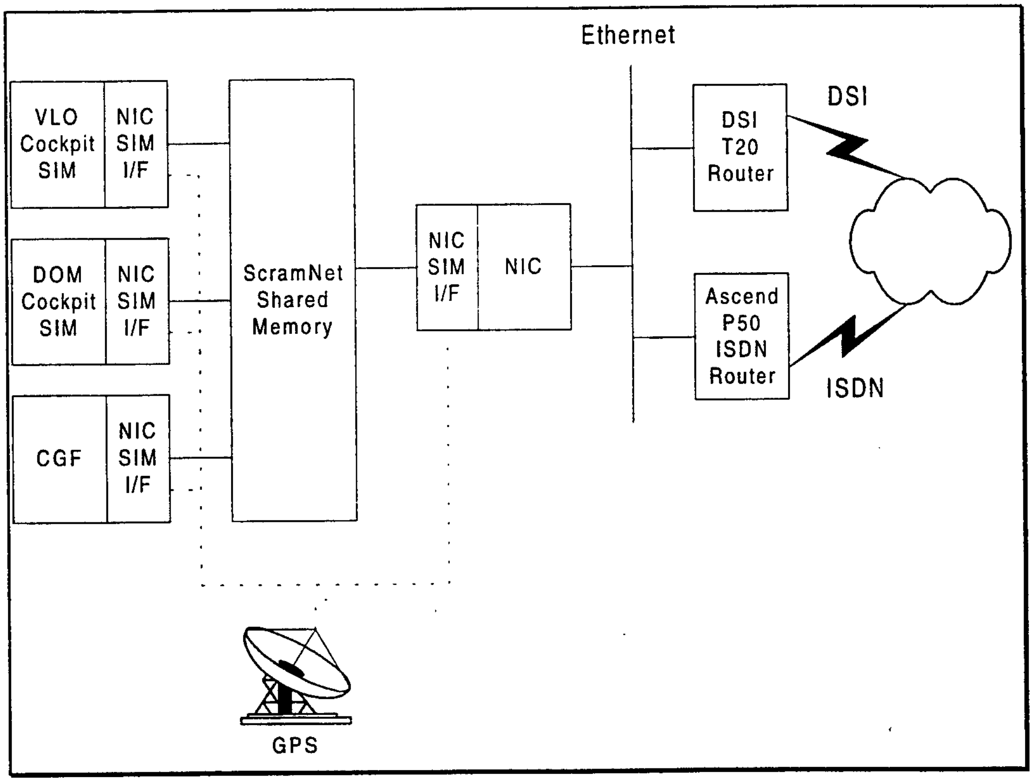


Fig. 3-47 Dasa NIC Computer configuration in Munich

The data exchange between the simulators and the NIC is accomplished via the object oriented NicSimInterface routines depicted below in detail.

3.2.3.1.1 Dead Reckoning

The main function of the NIC is to determine when new data received from the own simulator needs to be updated to the other participants in the simulation exercise. New entity position and orientation data from the own simulator (high fidelity model) are passed to the Dead Reckoning function. The last transferred position and orientation data are extrapolated to the time stamp of the new data (low fidelity model). If the error between the low fidelity model and the high fidelity model exceeds the specified threshold, the new data is marked for distribution over the simulation network. The important key here is that the new data is only marked for transfer and inserted or updated in a priority list (see chapter 3.2.3.1.2), but no PDU is built and output at this time. This is done in the "bundle PDU package" function below.

In the DASA Protocol an enhanced Dead Reckoning Algorithm is used. Orientation data is extrapolated according to angular velocity and angular acceleration whereas in DIS Protocol only first order extrapolation for orientation data is provided. Especially in high dynamic phases like the engagement phase of an air combat scenario, the enhanced Dead Reckoning Algorithm reduces network bandwidth requirements through lower update rates.

The Dead Reckoning for all foreign entities is done by the NicSimInterface method "updateNetEntities" (see chapter 3.2.3.1.2). When this method is called all foreign entities are extrapolated to the current time. Therefore, this method shall be called by the simulator immediately before the simulator works on this data.

3.2.3.1.2 Priority List

All data from the own simulator(s) which is marked for transfer to the other participants in the simulation exercise are managed in a double linked priority list. The highest priority data is found at the top of this list and the priority decreases to the bottom of the list.

The priorities for the own simulator data are ascertained either from the dead reckoning results (for kinematic data), from the importance of the changed data or from the minimum update rate.

The priority list is accessed when PDU packages are bundled and sent (see chapter 3.2.3.1.4).

3.2.3.1.3 Network Load Control

To control the network output load, the dead reckoning thresholds can be modified by the NIC. The following initialization parameters are used to control the network output load:

- lower and upper limit for the position and orientation thresholds for missiles
- lower and upper limit for the position and orientation threshold for all other entities (mostly aircraft)
- underload threshold for output data rate in kbit/s
- overload threshold for output data rate in kbit/s

The NIC allows separate thresholds for aircraft and missiles. Missile thresholds can be made higher than those for the aircraft without reducing the quality of the simulation. This again saves network bandwidth especially during peak load phases when almost everybody is engaged in an air fight scenario shooting missiles almost simultaneously at each other.

The position and orientation thresholds are modified according to the diagram below.

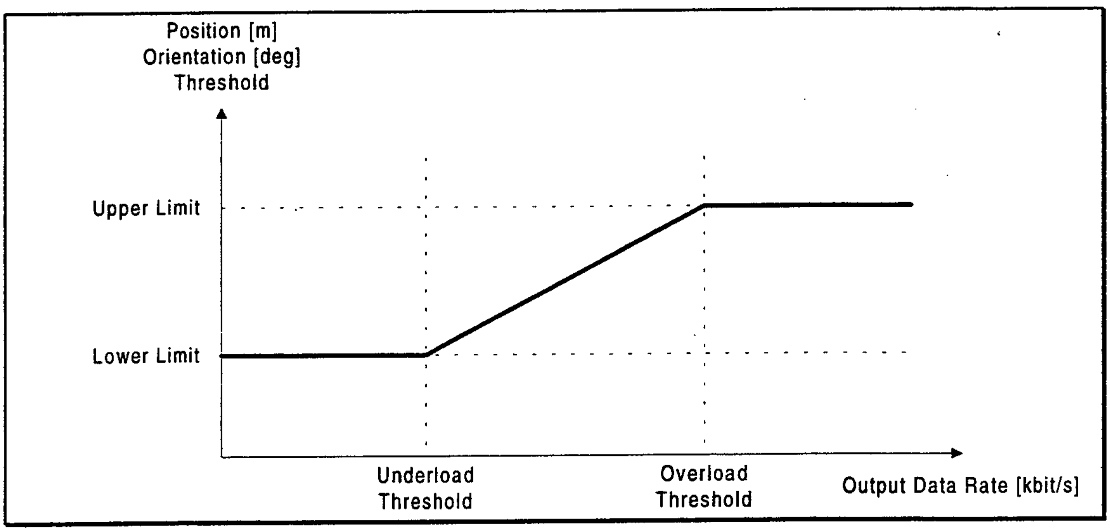


Fig. 3-48 Dynamic Dead Reckoning Thresholds

3.2.3.1.4 Bundle PDU Package

Bundling PDU's in a package reduces the network overhead and thus the network load.

The bundle PDU package function accesses the priority list (see chapter 3.2.3.1.2) to determine the highest priority data for output. PDU's are built from the newest simulator data and are bundled in a package until the package is full or the priority list is empty. Finally, the package is output to the simulation network. Only one package per NIC cycle is transferred. The NIC cycle time is 10 msec. Therefore, the maximum output packet rate is 100 packets/s. The PDU package size is a NIC initialization parameter. Through the definition of the PDU bundle size, the maximum network output load produced by one NIC is also given. Examples are shown below:

max PDU bundle size in bytes	max network output load in kbit/s
100	78
165	128
500	390

Adapting the maximum NIC network output load to the available network bandwidth will prevent network overload resulting in undeterministic packet losses and packet delay. A graceful degradation is thus achieved since overload conditions are solved by the NIC in a fully deterministic way. If necessary, PDU output is delayed by the NIC but finally when output, always the newest simulator data are output.

3.2.3.2 DIS- DIS-Lite-NIC

To use the DIS- and additionally DIS-Lite-protocol, special software modules were developed with support from the AFRL system and software engineers. These were based on the most recent version of VRLink's object library from Mak Technologies.

Both the DIS and the DIS-Lite module were designed to run on a FORCE SPARC CPU and to drive the interface of the DASA simulation.
Following are some TRACE-relevant modifications to the DIS and DIS-Lite protocols that were done to ensure complete coverage of the information exchange needed for some weapon system aspects:

⇒ only one system, one beam, one target used in ElectromagneticEmissionPdu

⇒ input radar intensity transmitted rather then output intensity

⇒ VLO/RaderType DIS/SystemName (Nr.0)

⇒ VLO/RaderMode DIS/SystemFunction (Nr.0) (note: VLO/RadarMode is not actually used)

⇒ VLO/MissileStatus AND VLO/BreakCondition for Missiles is transmitted in DIS/DetonationResult

⇒ No DIS/MarkingText transmitted

⇒ VLO/Role not transmitted

⇒ VLO/MissileNumber transferred via DIS/EntityType:Extra

⇒ VLO/Flares are transmitted via DIS/FirePdu

⇒ values are arbitrarily coded in:
VLO/Orientation.P0 - DIS/burst.quantity - number flares
VLO/Orientation.P1 - DIS/burst.warhead - flare type
VLO/Orientation.P2 - DIS/burst.fuze - ignition delay
VLO/Orientation.P3 - DIS/burst.rate - light intensity number

3.2.4 AFRL/VACD Guns Integration

The gun model provided by Air Force Research Laboratory was not incorporated at DASA because the necessary software changes in the Head Up display could not be incorporated in time for the production runs and the gun was considered to be a secondary weapon

4. TRACE Program Conclusions [Dasa & AFRL]

4.1 Lessons Learned

4.1.1 ISDN Standards

4.1.1.1 ISDN Computer

At the beginning of the related work Dasa provided a PC based ISDN router to the TRACE program as they have been used for European programs many times before. Within the PC there was a special ISDN router card installed supported by a software running under Novell-OS. The complete setup has to be performed under MS-DOS.

Configuring these routers for the TRACE program, i.e. for connecting US-ISDN, resulted in several problems and the support of the ITK hotline was insufficient. It cost a lot of time and work to figure out the failure roots, especially as promised functionalities could not be set up at all. After spending a great deal of time troubleshooting, it was decided to invest in a new and simple solution using Ascend Pipeline 50 routers, which limitations did not affect the TRACE program requirements.

Due to the ITK's more complex configuration processes, the following points should be considered when selecting a network solution:

<u>Installation /Service /Hotline</u>

- Complicated installation process
- Availability of the ITK hotline very arbitrary
- Questions concerning IP multicasting (if/when available) could not be answered sufficiently
- hard disk availability on the ITK router helped in troubleshooting (better than of Ascend without hard disk.)

<u>Channel-Bundling</u>

- problems when intermixing different versions and when using it with foreign countries (U.S., Switzerland, different standards) even with ITK's proprietary protocol.
- No multilink PPP supported up to now (see Outlook).
- No more than 2 B-channels will be supported (in the near future).

<u>Usability</u>

- For merely IP networks the usability is quite questionable because you normally need a Novell-network and a workstation on it to handle the router appropriately - Not having a Novell(IPX) workstation results in lot work arounds
- Update of S/W through public domain tool (NWSHELL) which often crashes
- Consistency insufficient

<u>Outlook</u>

- A new version was produced in Aug 97 called RAR4000 (and a "light" version MPR4.0) that implements multilink ppp allowing 2 B-channels to be bundled over ppp - which in turn allows a 2 B-channel connection with other routers like Ascend. No more than 2 B-channels will be supported at that time. According to ITK this is a problem of how the German Telekom supplies slots (a timing problem ?). The question is then how will router venders (i.e. Cisco) produce channel bundling over more then 2 B-channels (using the same German Telekom) We would need to approve channel bundling with more than 2 B-Channels with products like Cisco, Ascend.
- No Ascend or Cisco proprietary protocols will be supported with RAR4000 / MPR4.0.

4.1.1.2 ASTi - Dialogue Communications System

TRACE attempted to use the ASTi-Dialogue system for its voice communications-link via the WAN.

This report contains the results and conclusions of the communications-test-phase during March 1997.

- Data Compression Rate / Data Bandwidth
  Two compression algorithms are available with the ASTi-software: standard u-law and CVSD. When using standard u-law compression, the ASTi system requires a data bandwidth of approx. 100 kBit/sec., which is far too much to be useable within the TRACE-project. The CVSD-compression offers a significantly lower data bandwidth, approx. 40 kBit/sec., but yields a degraded voice quality. However, the necessary data bandwidth is still much higher than the theoretically achievable value of 12 to 16 kBit/sec., which is a strong indication of a high degree of system-specific overhead.
  However, the CVSD-data-bandwidth enables the ASTi system to be used when at least two 64-kBit-lines are available for connecting two simulators.
- Voice Quality
  The overall voice quality is low, but readable. Due to heavy timing problems induced by the transatlantic connection, the voice quality of the standard u-law compression is even less than the CVSD-compression. Distortion is around 10 percent, a high, but still tolerable value, but the background noise of the system (including the quantization noise) is very high and makes it impossible, to wear the headset over a longer period of time.
- VOX-control
  The VOX-control did not work properly due to threshold problems. The ASTi system was constantly sending out data packets, which lead to a data-overflow on the receiving site. It was therefore impossible to establish a two-way communication.
- PTT-control
  When using the Press-To-Talk control, a two-way (but half-duplex) communications-link had been able to be established.
  However, the Dasa-located ASTi-system did not have the necessary hardware extensions to enable the user to activate the PTT-control in a different way than by pressing a key on the ASTi-keyboard, which, of course, is impossible for someone in a simulator cockpit.
- ASTi Handling
  Due to the lack of being able to store the settings made during a session and the quite tedious initialization sequence, overall handling quality is poor.
  The store-option is available as an add-on, but was not supplied with the Dasa-located ASTi-system.

Conclusion

Due to the limitations and restrictions mentioned above, the ASTi-system in its current configuration was not useable within the TRACE-project.

Alternate Means

Currently, no other WAN-based communication system was available for the TRACE program. The use of a separate telephone line together with an analog communications system is suggested.

4.1.1.3 ELSA Vision Video Teleconferencing

For the TRACE Production Runs, it was planned to install a video conferencing system to support the effectiveness of the pilots briefing and debriefing phase.
An "ELSA Vision Video Conferencing System" was tried to setup and failed due to similar problems as for the installation process of the PC based ISDN-router. Again, the support of ELSA for solving transatlantic connection problems was insufficient. At least just a normal voice connection via a single ISDN B-channel could be set up.

Because this was not an objective of the TRACE program, no further studies for getting such a system running has been performed.

4.1.2 Model Fidelity Problems

The following subsections describe various model fidelity problems in the U.S. simulation that lead to an unfair advantage to the U.S. pilots when compared to the capabilities of the affected systems in the German simulation. The net result of this advantage was that the U.S. pilots achieved a greater number of kills than the German pilots in the tested scenarios. This mainly degraded the realism of the simulation and had little or no effect on the main purpose of the TRACE tests which is to investigate the capabilities of different long haul, networked simulation protocol and their potential application to air combat simulations.

4.1.2.1 US Performance Model

The aircraft model utilized in the U.S. simulation was an F-15C fighter performance model. The engine model internal to this F-15C model was based on an advanced capability engine. This had the result of giving the F-15C model greater performance capability than that of a standard F-15C. This provided the U.S. pilots with a distinct performance advantage over the German pilots during the simulated combat scenarios.

4.1.2.2 US Radar Model

The radar model utilized in the U.S. simulation was a subset of a complete APG-63 radar system. Due to model integration delays, only the Track-While-Scan (TWS) mode was available and Doppler effects were not yet included. The IFF system was a simplistic identification model that returned truth data for FFN ID and aircraft type for all radar tracks. The effects of terrain were also not incorporated in the radar model, although Dasa did provide the U.S. with a routine to determine if line of sight between objects was blocked by terrain. Unfortunately, this capability was not able to be integrated prior to piloted testing. The lack of complete radar model fidelity on the U.S. side resulted in the U.S. pilots having superior radar detection and tracking capability than the German pilots.

4.1.2.3 US LOS Checking

As mentioned in the previous section, Dasa did provide the U.S. with software to determine if line of sight between objects was blocked by the terrain in the Lake Mead database. This was intended to be utilized by both the radar model and missile models to provide for a more realistic simulation of terrain effects on detection and tracking capabilities. This capability was not able to be integrated with the U.S. simulation prior to piloted testing and resulted in the U.S. pilots having an additional advantage over the German pilots due to the fact that they were able to track, fire missiles at, and destroy targets that should have been protected by the terrain.

4.2 Recommendations

In Phase I of the TRACE Program a network architecture was defined and implemented using different networks and protocols.

Simulation facilities on opposite sides of the Atlantic ocean were networked to conduct integrated research and training simulations using existing, modified and, sometimes, newly developed technology.

The objectives of the program were:

- to perform USAF and MOD research into long haul simulator network technology by coupling the simulation facilities of AFRL and Dasa.
- to determine feasibility for developing a common American/German protocol optimized for Air Force applications.
- to conduct simulations showing the technical capabilities/limitations for potential operational use in aircrew training.

4.2.1 Networking the Simulations

Overall, it is possible in general to network the simulation facilities over the transatlantic distance. The following three media for the connection were surveyed :

- The ATM line (Asynchronous Transfer Mode)
  This media was not available for the transatlantic connection and additionally seems to be too expensive for the TRACE program. No performance data was measured.

- The DSI (Distributed Simulation Internet)
  A special connection using this media using a commercial 128 kbps ISDN was set up. The measured performance data for the usable bandwidth and delay times were poor. The connection to the network was quite complicated and was performed during the TRACE program via an additional ISDN line. Although this media, fiber optic cable, would provide a higher bandwidth, the entry lines (i.e. ISDN) will limit the bandwidth.
  The service was unreliable and the costs for the required bandwidth were relatively high.
  The response time of this media is insufficient.
  With the exception of the ISDN entry line, this media is secure.
  This media is no longer available outside the U.S.
- The ISDN- telephone line
  During the TRACE program, a standard ISDN telephone connection was established each time a test or production run was started. The German Telekom could not guarantee that the connection would always be set up via transatlantic cable, indispensable for a real-time simulation connection (because of the delay times). During the entire TRACE program, it is estimated there were probably only one or two times a connection was made via satellite.
  A fixed telephone line with a guaranteed use of the transatlantic cable connection would be available but then ISDN-configuration (i.e. channel bundling) is not ensured. Additionally, the cost is much higher for guaranteed transatlantic cable connections.
  Service and support are not needed and direct access of the simulation facilities is possible which eases network handling. The usable bandwidth is very high, the delay times are extremely low (ca. 100ms) and there is actually no response time. Additionally, the costs are low.
  The line is not secured at all and it is up to the user to perform encryption.

Overall the use of the standard ISDN is recommended if an efficient protocol is available.

As an ISDN-router, the "Ascend Pipeline 50" was a good and less expensive alternative to the PC based "ITK-ISDN-card" which had been used by Dasa for other network connections. This router's bandwidth covered the requirements of the TRACE program. However, additional tests are required to determine if more than two ISDN-B-channels are needed for higher bandwidth scenarios. Likewise, this router solution does not provide encryption functionality. For more complex scenarios with higher bandwidth needs and encryption requirements, new products in this fast developing router market can be expected in future.

Time synchronization of the connected simulations using a GPS-time signal was efficient and accurate.

The integration of the Dasa-NIC-HW and interface at AFRL was unproblematic and could be performed by AFRL engineers with some support by Dasa personnel via the telephone. The DIS- and DIS-Lite NIC could be developed at the Dasa site efficiently, as long as the AFRL personnel were able to support Dasa with the most recent version of the object libraries and additional information (any help and manual pages that were missing).

The voice link for cockpit communication could easily be performed using a separate telephone line as long as the cockpits of one simulation are not partly friendly to that of the connected partner. The planned "ASTI Communication System" was not reasonable for use due to its bandwidth need and is not recommended for use in further networking projects with limited bandwidth.

4.2.2 Common American/German Protocol Optimized for Air Force Applications

All surveyed protocols fulfilled the requested precision, and, with the exception of DIS-Lite, were usable for the developed scenarios with up to 4 vs 4 aircraft. The pilots themselves could not identify which protocol was being used during their training sessions as long as the bandwidth limitations did not cause positioning errors or simulation dropouts.

Some modifications to the DIS-protocols had to be done in order to transmit special air combat information such as dropping flares because neither the Dasa engineers nor the AFRL engineers could find a corresponding data package.

Since ISDN was the most reliable and least expensive networking media tested, the bandwidth is a very important factor in choosing a suitable protocol. Therefore, the Dasa-Protocol was determined to be the most efficient and predictable protocol, allowing for the estimation and extrapolation of bandwidth needs for even more complex scenarios.

4.2.3 Technical Capabilities/Limitations for Potential Operational Use in Aircrew Training

All operational pilots involved in the testing underlined the high value of the effect of training tactical maneuvers using interconnected cockpits in both local and long haul networks when combined with normal aircrew training.

Local combined simulations to a simulation cluster increase the training effect of

- mission planning and briefing,
- mission rehearsal,
- tactical maneuvering,
- communication,
- teamwork,
- missile avoidance maneuvering,
- debriefing.

Connecting such a simulation cluster to a distant force unit would extend training by practicing with

- unknown pilots
- different characters
- different types of aircraft (i.e. fighter with bombers)
- more complex and realistic scenarios.

The international connectivity used within the TRACE program enables pilots to effectively and inexpensively practice their international missions under the above aspects in a prephase training mission. Mission plans can be developed and proofed and the pilots can be trained on them.

Such systems can split necessary pilot training into

- basics such as communication training, which should mainly not be done airborne
- preparation and support of airborne training, to ensure best training effect for the small amount of remaining airborne flight training time.
- special maneuvers such as missile avoidance maneuvers which is very hard to practice airborne.

Special tools such as the Scenario Manager, with its recording and replay functionality, or analyzers support the pilots debriefing by repeating and visualizing each run, with the opportunity to repeat the whole scenario.

Limitations are set by the simulation models used. As the production runs show, it is absolutely necessary to use models that are as realistic as possible. Since the pilots must get an image of the situation by interpreting the outputs of the sensors such as radar and radar warning, the simulation must provide realistic outputs as well. Therefore, the sensors should emulate the sensors as closely as possible so not to adversely effect training nor undermine system acceptance

Likewise the aircraft and missile models must be realistic when considering missile avoidance maneuvers. If the missile model is not good enough, wrong maneuvers will lead to success, but only in simulation. The same applies to the aircraft model.

While in a local simulation cluster for tactical training highly realistic or even original models of aircraft or weapon systems can be used, long haul networked simulation cluster requires specific security measures. A new technology has to be developed to secure, reduce or adulterate such data exchange without reducing the training effect.

4.2.4 Conclusion

It was shown by operational American and German pilots that local and/or wide-area-networked simulation systems providing a realistic environment and involving a realistic number of participants add a new, high value method for training pilots. This method allows for tactical training in a squadron, both nationally and internationally, which was not available in a virtual environment until now.

Young pilots can train basics of tactical behavior with such systems and save valuable airborne training time for practicing just those maneuvers which can be performed in real flights only or can apply in training with the real weapon system what they have trained in the virtual environment before . Special combat situations can be repeatedly practiced together with the other wingmen of a force package. New tactics can be developed and refined.

Aspects of international joint missions like an alignment of communications, tactical behavior and mission planning can be practiced periodically, mission rehearsal of combined air operations is possible.

A further developed system like this will represent a good and flexible basis for international research and training programs using development and full mission or tactical trainer simulations.

4.3 Follow on Work

4.3.1 Potential German/US Follow-on TRACE projects

The TRACE network has significant potential to support future follow-on efforts between Germany and the US. The network could also be expanded to include additional players using similar techniques. The TRACE simulation network using ISDN digital network at 128Kb/sec has been optimized and introduces an average of only 100 ms. of additional simulation latency between Air Force Research Laboratory located near Dayton, Ohio, and Dasa located near Munich, Germany. With this excellent performance, the TRACE network can satisfactorily support a variety of simulation projects including training and research simulations. Except for the most demanding close-in interactive simulations, the TRACE network will support at least 4 entities. Both the German and US engineers working on the program are very pleased with TRACE's network simulation performance and would like to see the network used to its full potential in follow-on programs.

On September 16-18, 1997 a program review and demonstration was held at Wright-Patterson AFB. Potential follow-on efforts using the TRACE network were discussed. The sections below describe German and US interests and concerns regarding future work using the TRACE network.

4.3.2 German Interests and Concerns

The German emphasis is currently being placed on integrated training systems for highly dynamic aircraft training. The TRACE network could be used to support this area. The German MOD is supporting this goal through three programs. They are

1) VLO which is Dasa's ground based simulation that addresses combined air operations,
2) TRACE, and
3) WASIF (Weapon System Simulation in Flight), a project being executed under EUCLID (European Cooperation under Long Term in Defense).

The German portion of the TRACE project is part of a larger training project which supports fighter training.

TRACE has potential for training air forces. "Air crew training" and "crew assistance" are areas which are being emphasized in current German programs. WAS is a crew assistance program for the Euro-fighter. ATIMS is a carrier mission program which is aimed at mission planning. It is being conducted with the Navy who is interested in reducing workloads. It directly supports crew assistance and pilot training.

Several German programs are supporting simulation development and air crew assistance. These include Dasa's simulation programs, programs conducted by the University of German Forces, and a Mission Recorder under development from BGT in Germany and BVR in Israel. TRACE has expanded the state-of-the-art in long haul network technology development.

4.3.3 US Interests and Concerns

The US is interested in using the TRACE network to evaluate air vehicle systems such as UCAVs. There is a major Air Force thrust in the Unmanned Air Vehicle (UAV) area. There is significant interest by the US Air Force in this area, and there will be many in-house support activities. After the UAV programs have been better defined, there will likely be several areas which will need further development and will be good areas for cooperative international research. This type of research would complement US and German research.

Another US interest is to expand the TRACE capability by linking to an active combat range and evaluating the potential of the TRACE network to provide an essential research capability between test ranges and high fidelity simulations separated by long distances. Successful demonstration of this technology would establish a new capability for realistic international threat mission rehearsal via secure interactive networks.

During 1997, the US's efforts on the TRACE program were reviewed by Dr. Dix, senior representative from DDR&E. Funding for the US side has been provided primarily with 6.2 research funds through the AFRL/FIG Flight Control Division. The TRACE program was originally envisioned to be a comparison study between the German Automated Maneuvering System (AMS) and the US Integrated Control and Avionics for Air Superiority (ICAAS) combat pilot aiding systems. The TRACE program was broken into two phases to reduce risk. The first phase of TRACE was network development, and the second phase was to have been the comparative evaluation. Annex 1 of the umbrella MOU covered phase 1 of the TRACE effort. Dr. Dix perceived the TRACE program as only a networking effort and as contributing little to the US flight control and research efforts. His negative review has resulted in difficulty in funding TRACE work. Any follow-on effort will need to have a flight control emphasis or be funded through a different organization.

4.3.4 Summary

The TRACE network performance has the potential to support several types of future projects. The most promising projects include

1) joint training via long haul simulation,
2) UAV research,
3) expand TRACE network to include active air range, and
4) conduct comparative evaluations of air vehicle systems.

The German and US engineers agree that the TRACE network has significant future potential and want to actively pursue the future use of TRACE. Funding sources for such a program need to be identified.

TRACE is the only existing annex to the umbrella MOU between Germany and the United States, and it is hoped that future work can be identified to continue joint work. A new annex will need to be developed for any TRACE follow-on work. Annexes take some time to develop, and it is likely that formal program work could not be expected until 1999 at the earliest.

A couple of short term goals have been identified to maintain and promote the TRACE network while follow-on efforts are being identified. They include periodic testing of TRACE to ensure that simulation changes at either facility do not adversely impact the TRACE network capability. An occasional demonstration will also be presented so that the TRACE capability is maintained.

5. TRACE Evaluation Production Runs [Dasa]

5.1 Background

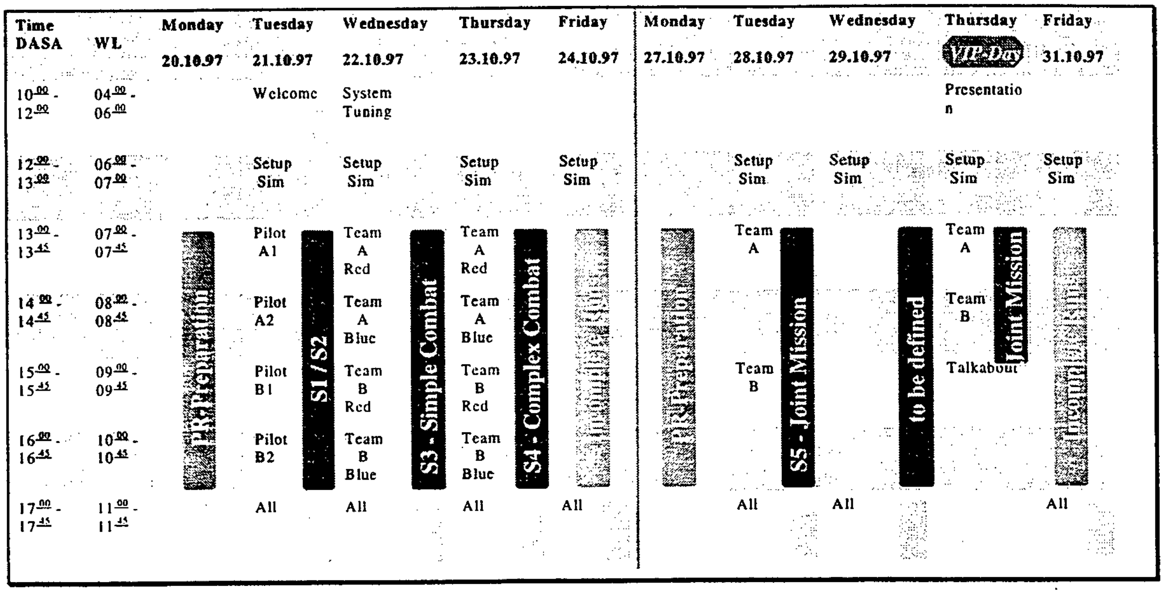


Fig. 5-1 Testing Schedule

For the TRACE Production Runs there were 4 days of test runs and a final demonstration in a period of two weeks scheduled. Due to problems in the AFRL image generator the scenario S3 and S4 were shifted to Monday and Tuesday of the second week. The originally planned scenario S4 was then delayed to the day after.

The complexity of the scenarios increased with everyday and ended with a joint mission scenario. For more complexity in the joint mission training sessions the number of Computer Generated Targets were raised up to 6. A simpler but more agile scenario was generated for an all versus all training described below.

An additional demonstration on both Dasa and AFRL side with the test pilots were shown in the following week.

5.2 Scenarios

5 different training and test scenarios were prepared for the production runs and completed by 3 new scenarios on request of the involved pilots. Scenario S2 to S4 were generated in the role of aggressors and defenders for both sides Dasa and AFRL.

5.2.1 Scenario 1: Pilot Familiarization

One cockpit of each side was active in this scenario . The cockpits were not hostile and placed on the same airport to fly nearby and formation. To ensure the pilots familiarization with the cockpit and the interconnected system, such a scenario were generated for all four cockpits. A voice connection was set up between AFRL and Dasa cockpits via separate telephone line what enables the pilots to talk to and get to know each other.

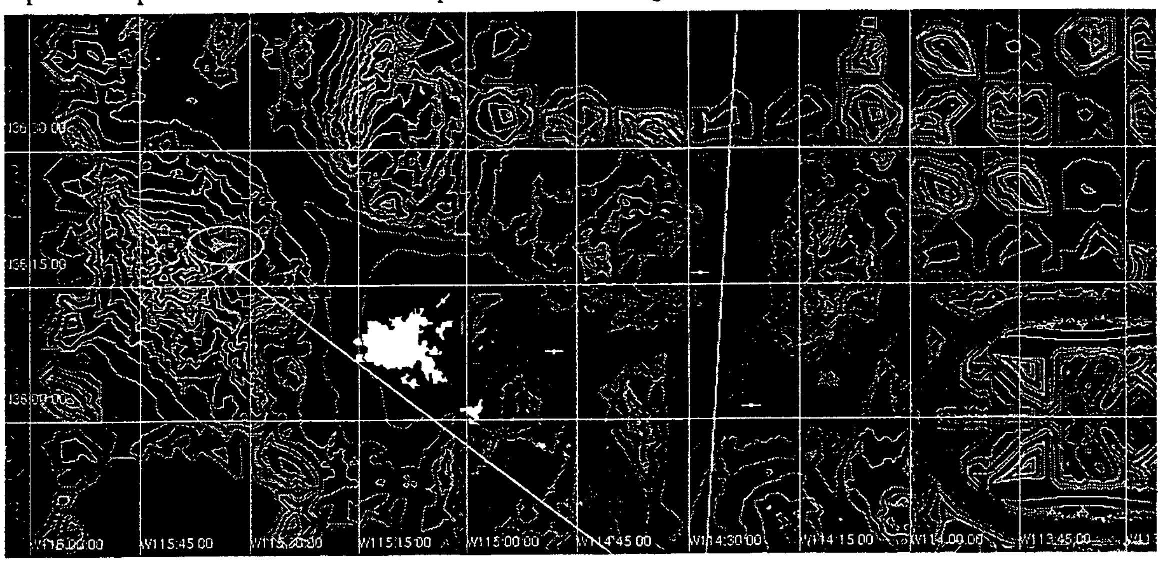


Fig. 5-2 Scenario 1 Map

2 A/C , 1 Airport

Key Points:

- ***2 Cockpits/ 1 Airport***
- ***Behavior of Entity***
- ***Getting familiar with the System***
- ***First Contact of Pilots***
- ***Testing Communication***
- ***Data Recording***

5.2.2 Scenario 2: 1 v 1 Combat

As in the scenario before, one cockpit of each side was active but this time hostile. Between AFRL and Dasa there was no communication system installed and the pilots were able to get familiar with the weapon systems of all cockpits.

Fig. 5-3 Scenario 2 Map

Key Points:

- ***2 hostile Cockpits***
- ***1 Airport, 1 Airborne***
- ***Getting familiar with weapon system***
- ***Data Recording***

⇒ Scenario 2A: 1 v 1 Combat (AFRL Blue, Dasa Red)

⇒ Scenario 2B: 1 v 1 Combat (AFRL Red, Dasa Blue)

5.2.3 Scenario 3: 2 v 2 Combat

In this scenario both the AFRL and Dasa cockpits were involved. The forces were hostile and no communication system between the forces was installed.

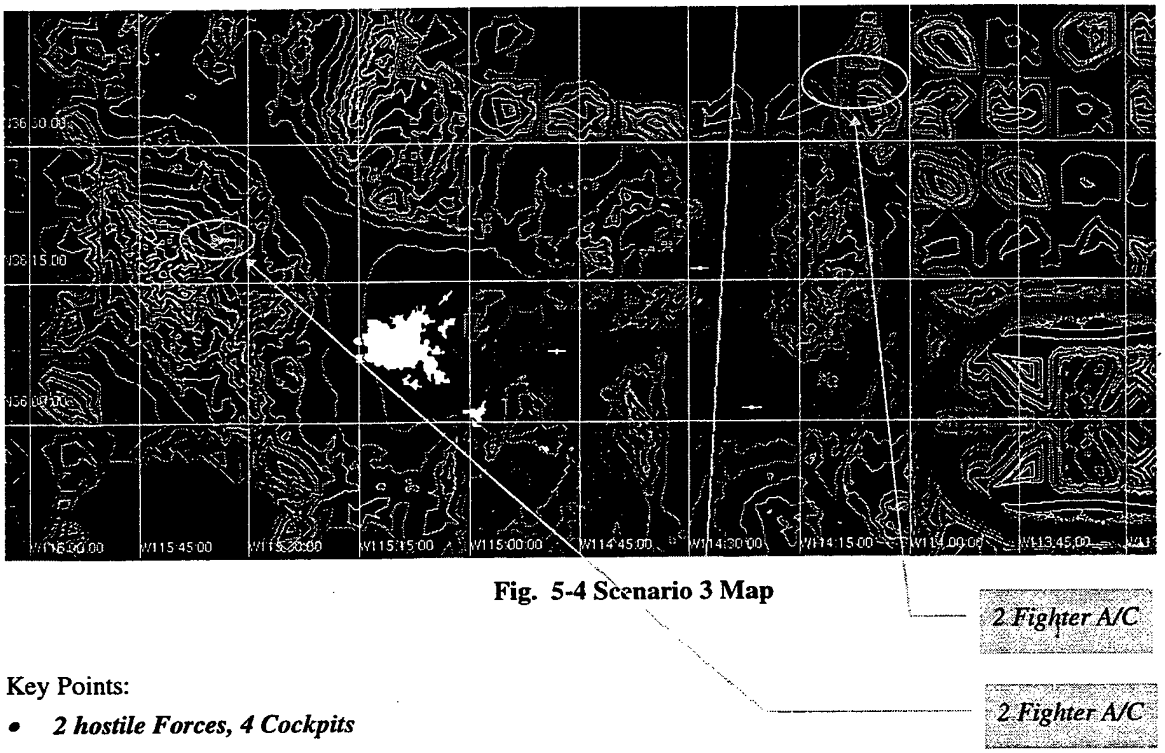


Fig. 5-4 Scenario 3 Map

Key Points:

- ***2 hostile Forces, 4 Cockpits***
- ***2 Airport, 2 Airborne***
- ***Combat Training***
- ***Data Recording***

⇒ Scenario 3A: 2 v 2 Combat (AFRL Blue, Dasa Red)

⇒ Scenario 3B: 2 v 2 Combat (AFRL Red, Dasa Blue)

5.2.4 Scenario 4: 4 v 2 + 2 Combat

In comparison to the scenario before, the complexity was increased by adding at the AFRL side two manned combat stations to their forces as well as adding two CGT's (Computer Generated Targets) to the forces on Dasa side. The aggressors were split into two separated forces.

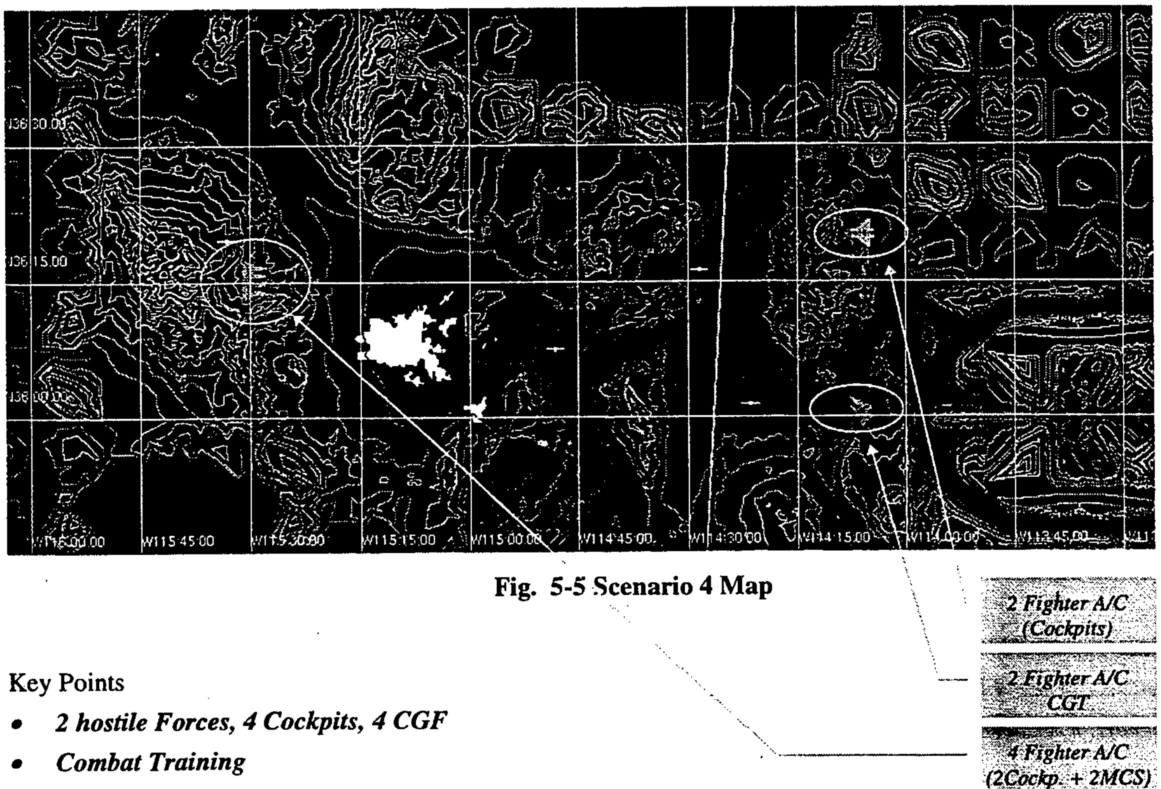


Fig. 5-5 Scenario 4 Map

Key Points

- ***2 hostile Forces, 4 Cockpits, 4 CGF***
- ***Combat Training***
- ***Data Recording***

⇒ Scenario 4A: 4 v 2 + 2 Combat(AFRL Blue, Dasa Red)

⇒ Scenario 4B: 4 v 2 + 2 Combat(AFRL Red, Dasa Blue)

5.2.5 Scenario 5: 2 + 2 v 4 Joint Combat

In this scenario all 4 simulators had a joint mission against 4 CGT's. Two simulators were controlled by AFRL and the other two and all four CGT's by the Dasa simulation. The hostile forces were split into 3 fighters and 1 remotely located bomber as aggressors. The joint mission team had 4 fighters.

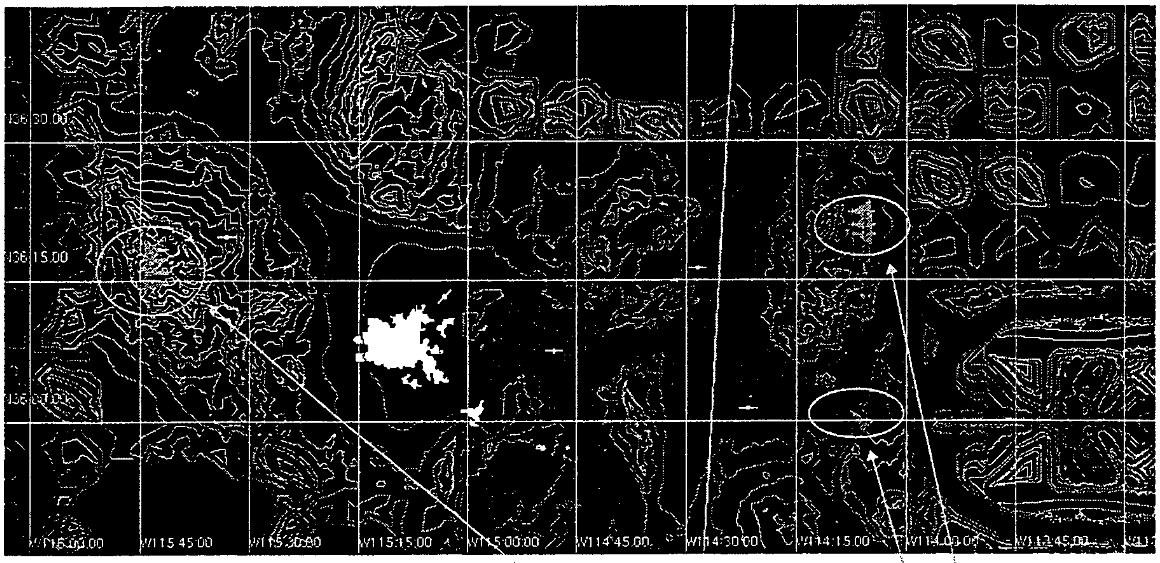


Fig. 5-6 Scenario 5 Map

Key Points

- ***2 hostile Forces, 4 Cockpits vs 4 CGF***
- ***Combat Training***
- ***Data Recording***

5.2.6 Added Scenario

On demand of the pilots, more complex scenarios were developed to increase the effectiveness of the tactical training for joint missions by increasing the number of involved entities.

The interconnected system shows its flexibility and performance with the Dasa-Protocol. For the usage of the DIS or DIS-Lite-protocol the bandwidth need was too high for that high number of possible entities.

5.2.6.1 Added Scenario: 2 + 2 v 6 Joint Combat

This scenario was similar to the S5 but with the increased number of 6 Dasa controlled CGT's. Due to bandwidth limitations it was only performed by using Dasa protocol.

5.2.6.2 Added Scenario: 2 + 4 v 6 Joint Combat

This scenario was similar to the S5 but with the increased number of 6 Dasa controlled CGT's and another two manned combat stations at AFRL. Due to bandwidth limitations it was only performed by using Dasa protocol.

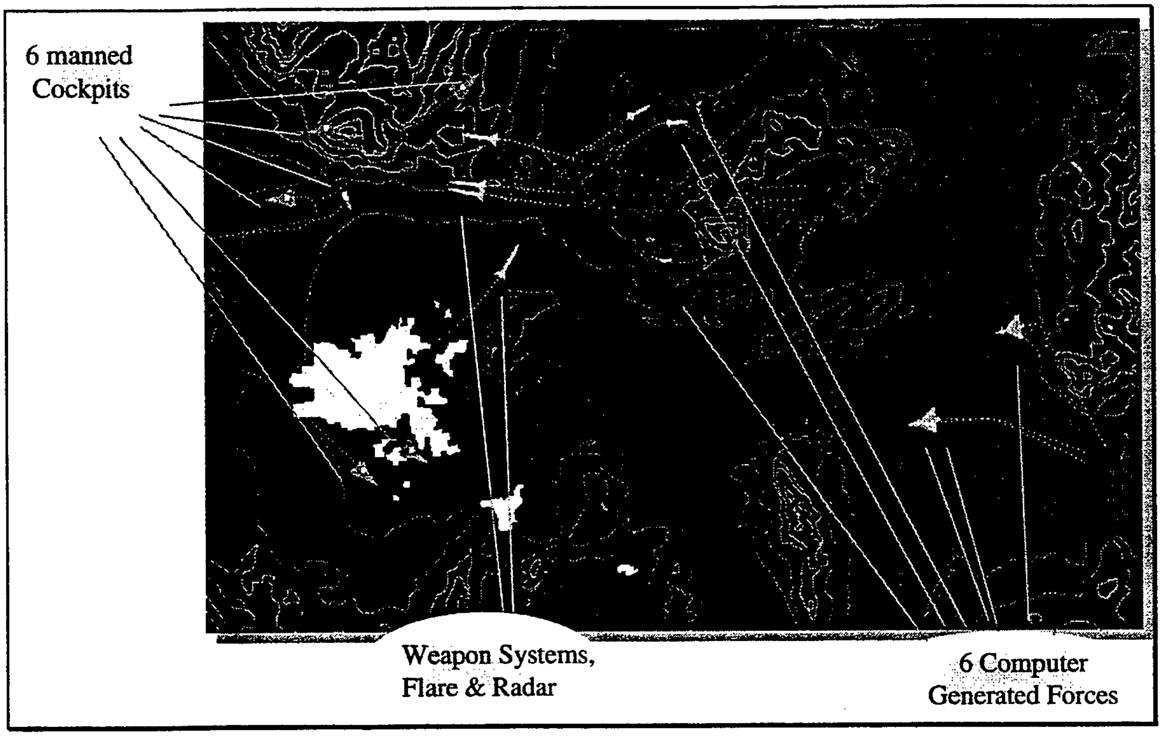


Fig. 5-7 Snapshot out of the 2 + 4 v 6

The figure represents a snapshot out of the 2 + 4 v 6 scenario and shows about the highest complexity of the training session which could be handled via a single ISDN telephone line using Dasa protocol, although the dispersion of the entity control was unbalanced towards the Dasa simulation which handled 2 simulators and 6 CGT's and all their weapon systems and missiles.

5.2.6.3 Added Scenario: 1 v 1 v 1 v 1 Combat

This is a usual training scenario for flight training. All four entities start the training at the same distance from a virtual point on the map. Every entity fights against every other one. Only SRM's are allowed and may only be used if you are directly behind the hostile target.

This scenario was a proof of the high resolution ability for data loss, transferring failure, reliability of the interconnected system and a little bit of fun for the pilots.

6. TRACE Network Connectivity [Dasa & AFRL]

6.1 Network Background

6.2 AFRL/VACD & Dasa Physical Network [Dasa & AFRL]

6.2.1 AFRL/VACD Local Network [AFRL]

6.2.1.1 Normal AFRL/VACD Network

The AFRL/VACD computer deck normally has two separate Ethernet networks, one for routine network traffic and one for real-time network traffic. All of the Silicon Graphics and Encore 91 computers default Ethernet interfaces are connected to the "default" network. In addition each Silicon Graphics used for real-time has a second Ethernet interface that is connected to the real-time network. The Encore RSX computers have one Ethernet interface which is connected to the real-time network. The TRACE program utilized the real-time network to drive the AFRL simulation displays.

6.2.1.2 Added Network Components for TRACE

The only addition to the local network at AFRL was the connection of one of the Challenge's E-Plex Ethernet to a hub for connectivity to the ISDN or DSI long haul networks. This connection was used for the DIS and DIS-Lite protocols. The port was configured differently for use with the DSI and the ISDN as shown in Table 6-1

Network	IP Address	Routing
DSI	172.17.0.20	N/A
ISDN	172.18.230	route add net 172.17.0.0 172.18.0.254

Table 6-1

6.2.1.2.1 Dasa NIC Computer

The Dasa NIC Computer at AFRL is comprised of a Force VMEbus rack connected via ScramNet to the AFRL Simulators and connected via Ethernet to the WAN interface, an Ascend Pipeline 50 ISDN router (2 B-channels, total bandwidth 128 kbit/s).

6.2.1.2.2 SNAP Computer

SNAP grew out of a need to determine the ability of current DIS networks to handle the high fidelity networked simulations required by the Air Force. This project focused on the time delays and simulation accuracies associated with networked simulations over long distances, (or "long-haul simulations") for highly dynamic vehicles.

There are several time delay issues that SNAP addresses. Total end-to-end network delays are important to know (to remain under the 100ms rule of thumb), but latency values at certain subsections within the overall network are equally as important. Other latency issues include time correlation of cues, and how a pilot in one simulator perceives aircraft actions at a second simulator. To determine the time delays associated with the network for these types of issues, a portable timing analysis unit (SNAP) was developed. To help with SNAP, an Electronic Visual Display Attitude Sensor (EVDAS) was also developed to measure when the pilot's visual display received updates. These two units, together with the associated software, make up the SNAP system (Figure 1).

One SNAP computer can operate alone to determine several performance factors of a single simulator; such as stick input to out-the-window (OTW) video delay, stick-to-instrument delay, stick-to-state variable update delay, stick-to-Protocol Data Unit (PDU) transmission delay, PDU reception to state variable update delay, and PDU reception to OTW video delay. Also, multiple SNAP computers can evaluate the performance of a networked simulation by connecting to simulators in geographically separate locations and monitoring the end-to-end delay. SNAP can also monitor a network and give statistics on network traffic; from generic Ethernet packets to particular PDU types.

SNAP is capable of driving repeatable simulator input signals, allowing the SNAP operator to have repeatable test results. SNAP's measurements between simulators located anywhere in the world is accurate to within 500 microseconds.

To accurately obtain data from a simulator, SNAP is capable of operating synchronously (i.e. sample data consistently at the same time slice within the frame) with a simulator in two different ways. The first is to synchronize SNAP's sampling time with the simulation computer's frame time using an external interrupt. The second method is for SNAP to synchronize with the refresh rate of the video display system connected to EVDAS. SNAP is also capable of sampling at a configurable frequency independent from the simulator, although this is usually undesirable (but occasionally useful when obtaining the interrupt from the simulator is too difficult). SNAP can be configured to collect data using any combination of sampling methods previously mentioned, but wherever practical, SNAP should be used in synchronous mode to avoid asynchronous sampling problems.

The SNAP computer is a rack mounted 150 MHz Intel Pentium PCI/ISA bus system with an integrated 9.4" SVGA LCD display and a 270 Mbyte SyQuest removable cartridge drive. The SyQuest cartridge can be removed and secured if it contains sensitive information.

The computer's expansion slots house several off-the-shelf PC cards and an in-house developed EVDAS card. The off-the-shelf PC cards include a multi-function input/output board, two Ethernet boards, a global positioning system (GPS) board, a SCRAMNet shared memory board and a SVGA video card.

SNAP, through National Instruments' multi-function I/O card, has two analog signal outputs, eight differential analog signal inputs, and four digital I/O channels (16-bit, 4-bit, 2-bit, and 1-bit). The multi-function board provides several counters/timers for frequency and event counting. The board also has an external sync input capability. This board is used to drive stick signals and/or record simulator state variables.

3Com Ethernet boards are used to passively extract PDU information from any network running DIS. Using two Ethernet boards enables a single SNAP computer to monitor PDU traffic at two different points within a single simulation site.

The GPS receiver, which is accurate to within 2 microseconds, is used to correlate remotely gathered data when multiple SNAP machines are used on long-haul simulations. SNAP's GPS receiver is composed of a PC plug-in card, an antenna/receiver, and a GPS synchronized timing module.

The SCRAMNet card is used to read state variable information from a simulation network using this type of architecture.

The SNAP computer operates with Intel's RMX (iRMX) real-time operating system with MS-DOS running as a task. The iRMX operating system allows for real time interrupt-handling and precise timing of collected data. An MS-DOS sub-task is used to run the Graphical User Interface (GUI). The GUI allows the user to control SNAP's hardware and software. The GUI was developed using National Instrument's LabWindows. Additionally, custom analysis software was developed to quickly process the data files and assist in producing a report.

The second major hardware component of the SNAP system, EVDAS, was designed, developed, and constructed in-house. EVDAS consists of an interface card (located in the SNAP computer) and a measurement unit (EVDAS box). The EVDAS interface card provides the necessary digital information based on video signals passed between the EVDAS box and the SNAP computer. The EVDAS interface card also contains a highly-stable microsecond crystal clock used for accurate time stamping (by the SNAP computer). The EVDAS box detects motion in visual images, such as wing tips or the horizon and sends this information to the EVDAS interface card.

The SNAP computer and EVDAS box were integrated into the AFRL facility to allow for the measurement of various simulation latencies.

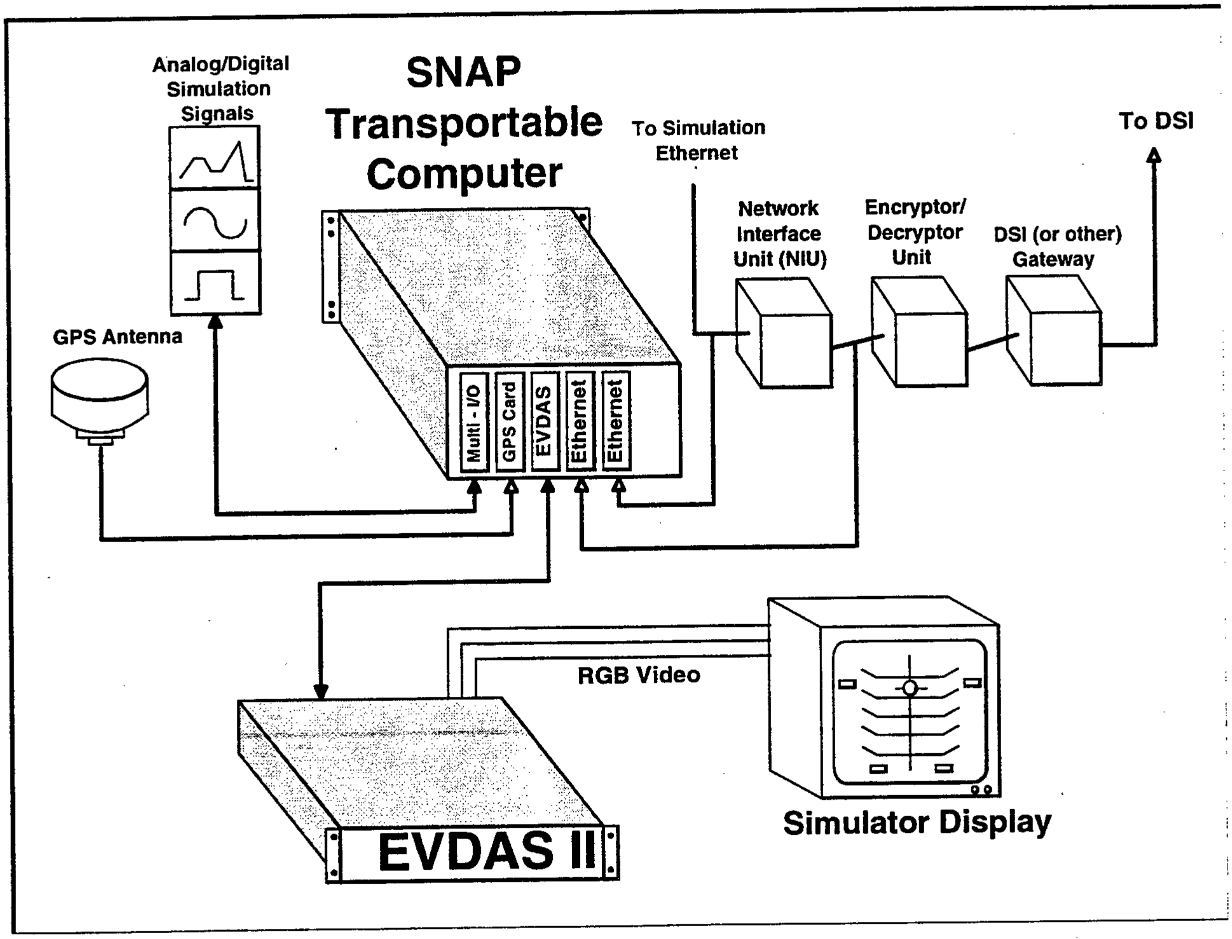


Fig. 6-1 SNAP Description

6.2.2 Dasa Local Network [Dasa]

For the TRACE program, an ISDN line was connected to the ISDN Router allowing secure access from the WAN. The ISDN router routes the WAN into a general local network where the ASTi Voice communication system, the SNAP equipment and the NIC computer are connected. For the production runs the ASTi communication system was replaced by a simple telephone link between the local communication systems on both sides. In addition to its normal functions, the NIC computer acts as a gateway between the WAN and LAN and connects to LAN 2 over the firewall.

The LAN 2 network connects the VLO simulation components (VLO simulator, CGF's, Data Recorder) with the development system and the Network Interface Computer (NIC).

The NIC in this diagram represents the Dasa-NIC and the DIS- and DIS-Lite NIC that was developed for the TRACE program.

No gateway exists between the Dome Simulation and the VLO-Simulation networks.

Data is exchanged between the simulations via SCRAMNet shared memory. Data exchange between the SCRAMNet interface and the VLO components and between the components themselves is performed via local shared memory.

The SNAP equipment was connected to the system via a SCRAMNet interface for real-time data sampling and by Ethernet for PDU collection.

The Dasa Scenario Manager was modified and special configured via a second NIC for the TRACE program. This common initialization not only runs using the Dasa protocol but also the DIS and DIS-Lite protocols. Additionally, it enables the operator to record and replay the training sessions for all used protocols, although it is designed primarily for the Dasa protocol.

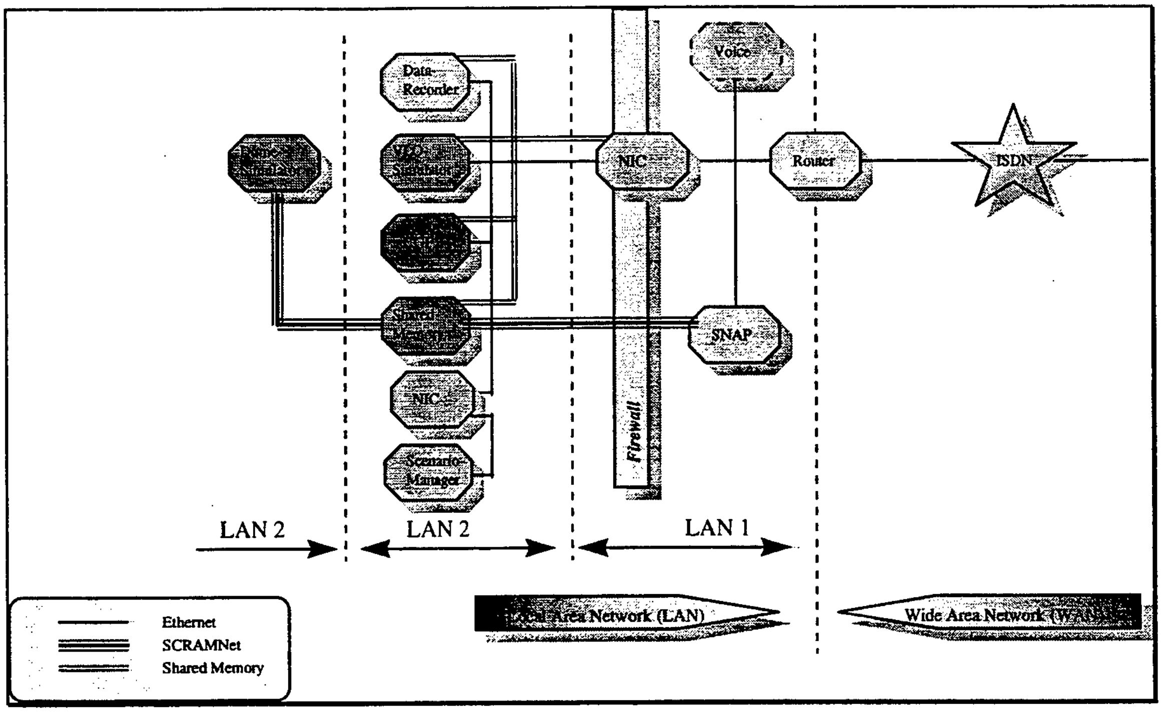


Fig. 6-2 Dasa local network configuration

6.2.2.1 Dasa NIC Computer

The Dasa NIC (Network Interface Computer) is a portable software module which runs on several platforms and is used to ensure overall compatibility across the entire VLO simulation network. For the TRACE program, this module was implemented within the Scenario Manager and on standalone computers. Two NIC's were used in the local Dasa simulation network and one NIC was used at AFRL.

The Scenario Manager ran on a Silicon Graphics platform with all the NIC's running standalone on FORCE VME-platforms with Sparc CPU's.

At Dasa, one NIC was used to connect the local simulation via ISDN to the AFRL simulation's single Dasa-NIC. The second NIC was used to connect the Scenario Manager with its standardized Dasa-Protocol to the TRACE simulation net.

If the DIS- or DIS-Lite protocol was used for WAN-connection, the Dasa-NIC connected to the ISDN router was replaced by the DIS / DIS-Lite NIC (same hardware different software).

6.2.2.2 Added Network Components for TRACE

6.2.2.2.1 SNAP Computer

The SNAP equipment provided by AFRL was connected to the Ethernet network between the WAN router and the NIC, to the SCRAMNet interface, to the video display system, to the control stick and to an interrupt signal provided by the Dasa simulators. The Ethernet connection allowed SNAP to collect and timestamp transmitted or received PDUs for later analysis. Before connection SNAP's SW was modified to allow it to collect all three protocol's PDUs. This modification amounted to the addition of code to collect Dasa PDUs. The SCRAMNet connection allowed SNAP to collect and timestamp data placed into SCRAMNet shared memory. Since SCRAMNet was used to exchange local data between the VLO- and the Dome-Simulators and represents the shared memory HW of the VLO simulation, this data was the simulator's (simulated aircraft and missiles) state data (roll, roll rate, pitch, etc.). The connection to the video display system allowed SNAP to capture and timestamp changes in the pilot's video display. This is used to indicate when the result of a control stick input is depicted on the pilot's visual display. The connection to the control stick allowed SNAP to either record (sample) stick inputs or to drive stick inputs. Sampled stick inputs or SNAP induced stick inputs are recorded and timestamped allowing for measurements of delays

through the simulator. The last connection, the interrupt signal from the Dasa simulator, is used to synchronize SNAP's data sampling to the simulator. Using these connections, SNAP's data can be used to calculate the delay between a stick input to a resultant state change, to a visual display change and to PDU transmission. Additionally, SNAP's data can be used to calculate the delay between the reception of a PDU from a remote site to the resultant change in the remote entity's local state variables and remote entity's local visual attitude change.

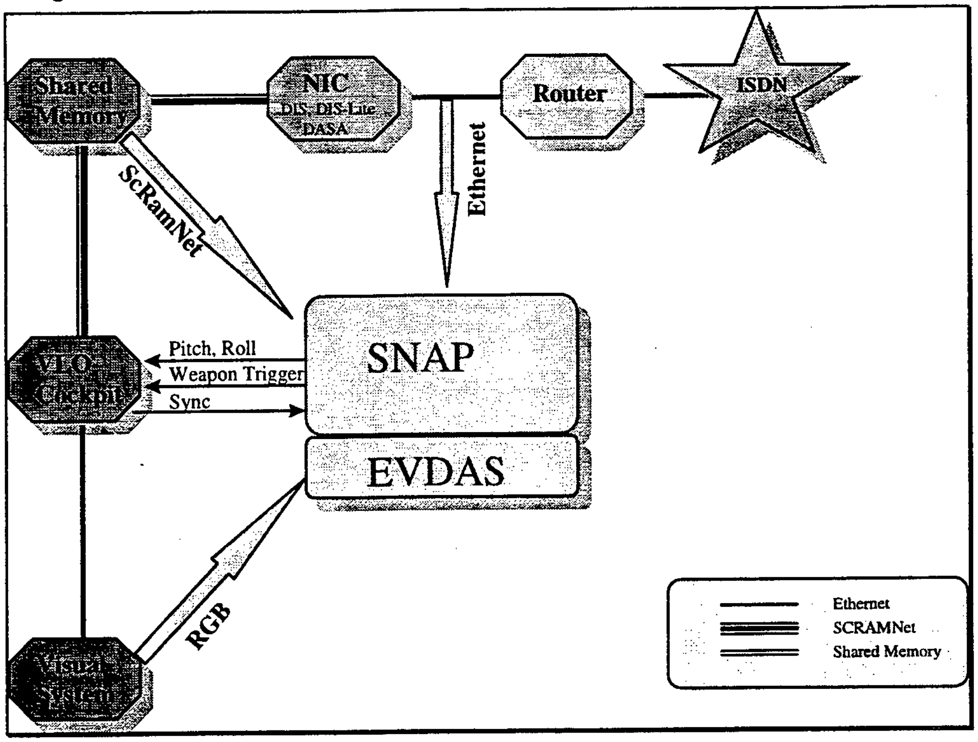


Fig. 6-3 Dasa-SNAP-Configuration

6.2.2.2.2 DIS-, DIS-Lite-NIC

For the TRACE program, a DIS- and a DIS-Lite NIC-SW-module were developed based on Mak Technologies object library ensuring compliance with the DIS standard protocol. These modules, physically installed on the Dasa NIC-HW, replaced the Dasa-NIC SW module during the TRACE tests.

6.2.3 AFRL/VACD & Dasa Long Haul Network [AFRL]

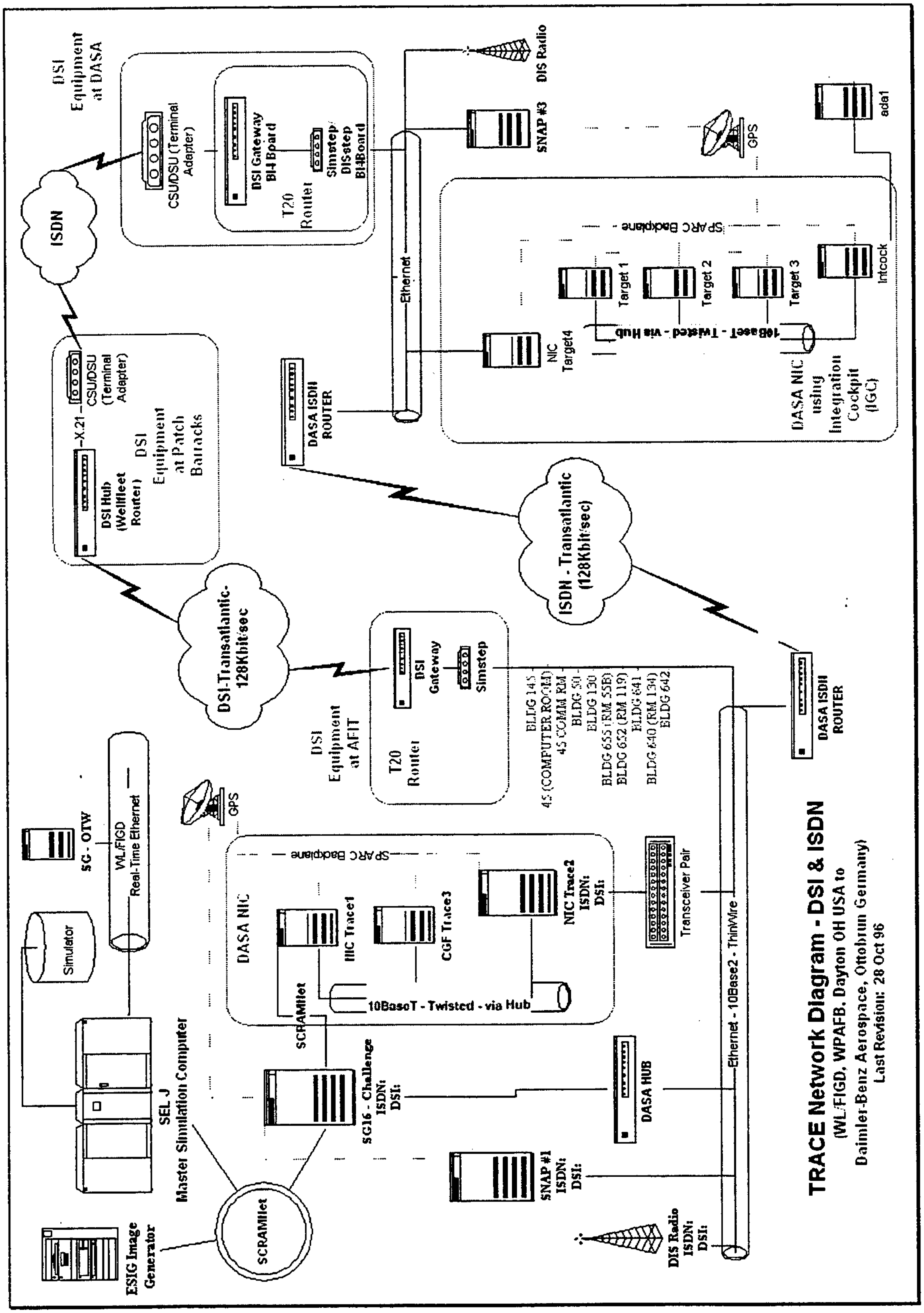


Fig. 6-4 TRACE Network Map

6.2.3.1 Defense Simulation Internet

In addition to a standard ISDN telephone line, a simulation connection using the DSI (Defense Simulation Internet) was tested. DSI equipment was installed at Daimler Benz Aerospace AG for several months. Since Dasa had no direct connection to the DSI, an ISDN tail circuit (entry point) was established to connect them to the DSI hub near Stuttgart. This limited the DSI bandwidth to a theoretical 128 kbit/sec. Prior to the production runs DARPA/JPO removed the DSI not only from Dasa but also from Germany preventing it from being a candidate for use during the production runs. However, prior to its removal, based on the DSI's achieved transfer rates, delay times, handling and availability, the DSI was determined not to be the best choice for use in the production runs.

All the measurement data reported herein refer to the actual data rates and do not consider any overhead by any non-application protocol (IP, UDP, Streams)

- Throughput
  In the week starting with 1 April 1997 we achieved a bandwidth of 74 kbits/s. In previous connections, we barely reached 60 kbits/s at a very maximum. The results were obtained using several different packet sizes and buffer sizes (buffer size is established to allow some kind of burst mode) to look for the best values.

- Delay-Times
  At an estimated average, we do get 300ms round-trip time, which is 150ms one way and 50% above the maximum specification time (as given in the DIS standard). Typical rates were 270ms up to 380ms. These values were obtained with either a test program which works in very much the same way that our application works [using UDP rather than TCP]) or with a standard ping command. There is no real difference observed between these two methods.

- Availability
  The estimated availability was about 50% of the scheduled time. The DSI was scheduled up to a week in advance but could be scheduled up to one day in advance of any tests. On the day of testing, Dasa would create the ISDN connection to the DSI using a CSU/DSU supplied by the DSI administrators. Many times this connection would fail and the network support center would be called to determine the cause and means to correct the problem. If the ISDN connection was successful, many times we found that the routers at Vaihingen or Ramstein would be experiencing problems, thus yielding no network. This would often take several hours to correct (if corrected at all) and often resulted in the rescheduling of the test or changing to the ISDN network to perform scheduled tests. Often after a successful network connection, the streams would fail, the ISDN connection would drop out, or the routers would experience problems thus dropping the network connection.

6.2.3.2 Integrated Services Digital Network

6.2.3.2.1 ISDN Router

The first attempt to connect via an ISDN line used a PC based ISDN router. This router consisted of a Pentium computer configured with a ISDN router card manufactured by ITK Germany. This setup required additional ITK-router-SW running on Novell-OS for configuring the card. The system was difficult to install because it used software running under Novell-OS but installed and started from a DOS platform. Additionally, many of the promised features and functions could not be setup. It was impossible to bundle the two ISDN B-channels to achieve the required 128 kbit/sec bandwidth. This was a result of the difference in the European and American ISDN standards and switches. Because of this, the PC based ISDN router could not be used for the TRACE project even though it had been successfully used by Dasa in many European projects.

Instead, the "Ascend Pipeline 50" router was selected and implemented. It was easy to install, more efficient and a reliable alternative.

6.2.3.2.2 ASCEND Pipeline 50 Router

The original agreement was to use the Defense Simulation Internet and a commercial ISDN line for TRACE network connections. The two networks were to be compared and the better of the two chosen for use during the production runs. Since AFRL had no experience with ISDN, it relied on its local telecommunication company to suggest both

the type of ISDN and type of ISDN terminal adapter. The resulting ISDN Basic Rate Interface with 2 64 kbps B-channels and 1 16 kbps D-channel were suggested and connected. Ameritech, the local telecommunication company, also suggested the ASCEND Pipeline 50 ISDN router. This router was purchased but not connected immediately, opting for the Dasa provided ITK ISDN router described above. After discovering that the ITK router would not fulfill the network needs, Dasa purchased an ASCEND router and implemented it on their side. After some minor modifications to the router setup the two ASCEND routers connected to one another with both B-channels providing the required 128 kbps bandwidth. Some limitations were not overcome however. AFRL and Dasa were unable to provide password security for their router connections (time limitations prevented the full familiarization with the routers). This did not present a problem since the routers were disconnected from the ISDN phone line at the end of each day (this was not only to prevent unauthorized access but also to prevent the ASCEND routers from connecting to the distant network unknowingly).

6.2.3.3 Asynchronous Transfer Mode

At the kickoff meeting the use of an Asynchronous Transfer Mode (ATM) network was discussed. These fairly new network offering "bandwidth on demand" with bandwidths up to OC12 (600 Mbits/sec). In researching the availability of ATM networks it was discovered that the monthly cost was very high and above the capability of AFRL to implement. Therefore, the decision to not include ATM as a network option was made.

6.3 AFRL/VACD & Dasa Network Communication [Dasa & AFRL]

6.3.1 Distributed Interactive Simulation Protocol [AFRL]

The IEEE 1278.1-1995 DIS protocol used for these experiments specifies the data fields for IEEE 802.3 (Ethernet) packets known as Protocol Data Units (PDUs). PDUs are transmitted over the network using User Datagram Protocol/Internet Protocol (UDP/IP). This is shown in Figure 3.1.

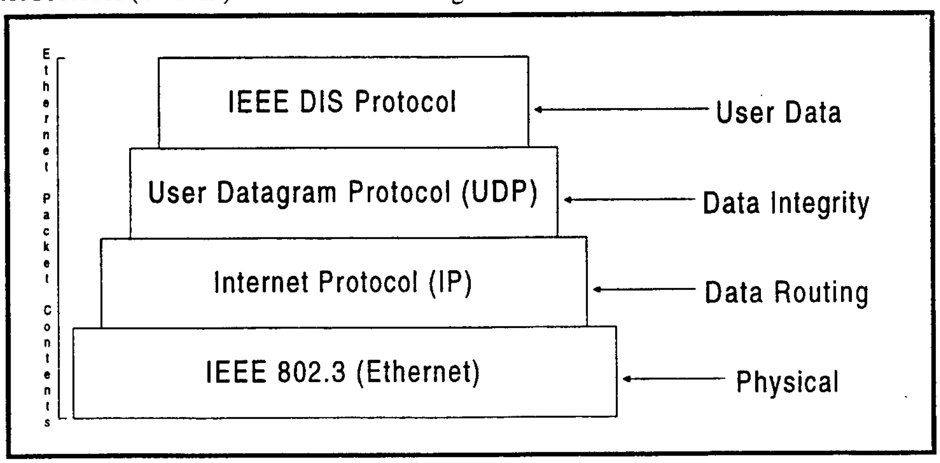


Fig. 6-5 PDU Construction

PDUs come in many different types; each type is designed to communicate a specific piece of simulation information to other simulation sites. The most common PDU type, the Entity State PDU, is designed to convey the locally simulated "entity's" (combatant) "state" (location, velocity, acceleration, roll, pitch, yaw, etc.) information to other (interested) simulators. Other PDU types announce a weapon firing, a weapon detonation, entity collision(s), radio transmissions, radar and other electromagnetic emissions, simulation control (start, stop, freeze, and resume), and logistics. Whenever a simulation has such information to send to other simulation sites, it processes the information, formats it into the PDU format, and sends the PDU out over the network to the other simulation sites.

PDUs are typically broadcast over the network. That is, the information is not destined for a single simulation site, but rather it is sent to every simulation site on the network. It is up to the local site to filter out, or ignore, the PDUs it is not interested in. For example, an Army tank simulation might filter out Navy ship simulation PDUs, as the tank simulation does not require ship simulation information to function properly (unless the Army tank is near the Navy ship).

Filtering network traffic is a critical process. Physically, computer systems have limited memory and processing capability. While memory space continues to increase and processing capabilities grow, a large network simulation (like Warbreaker or the Synthetic Theater of War exercises), containing thousands of entities generating many thousands of PDUs during the course of the simulation, could easily overwhelm a simulation computer with information. Filtering reduces the simulation computer processing workload so it may concentrate on performing its own simulation rather than processing the network traffic. Often, a separate computer is used to access the main network - even in this case, it is wise to filter out unimportant entities.

Similarly, a process known as "dead reckoning" is a crucial part of the DIS protocol suite. Without dead reckoning, each entity is required to continuously transmit its state information to the other simulation sites, resulting in flooded networks choked with information. DIS uses dead reckoning to reduce the information transferred between sites. Each individual site maintains a "copy" of both its own and the remote simulation entities. Based on past knowledge, the local simulation site predicts (extrapolates) the current and future states of the entities (dead reckons), and unless new information is given, the local simulation assumes the entities are where their dead reckoned positions places them. The dead reckoning algorithm utilizes a user set threshold for angular and positional errors. If the dead reckoning threshold is not exceeded, the aircraft state is typically updated at a 5 second time interval (often called a "heartbeat"). This process, while greatly reducing the amount of network traffic, causes severe problems with endgame situations. Often, weapons run on the local simulation computer will claim a hit based on the dead-reckoned network entity. However, the target aircraft might have escaped the weapon's attack by performing some maneuver that the dead-reckoning wouldn't account for, leading to a "I-hit-you-no-you-didn't" issue with negative training implications.

Entity State PDU Format				
Header	Protocol Version (8-bit enumeration)	Exercise ID (8-bit enumeration)	PDU Type (8-bit enumeration)	Padding (8-bit enumeration)
	Time Stamp (32-bit enumeration)			
	Length (16-bit enumeration)		Padding (16-bit enumeration)	
Entity ID	Site (16-bit enumeration)		Application (16-bit enumeration)	
Force ID / Art Parts	Entity (16-bit enumeration)		Force ID (8-bit enumeration)	# Articulated Params (8-bit enumeration)
Entity Type	Entity Kind (8-bit enumeration)	Domain (8-bit enumeration)	Country (16-bit enumeration)	
	Category (8-bit enumeration)	Subcategory (8-bit enumeration)	Specific (8-bit enumeration)	Extra (8-bit enumeration)
Alternative Entity Type	Entity Kind (8-bit enumeration)	Domain (8-bit enumeration)	Country (16-bit enumeration)	
	Category (8-bit enumeration)	Subcategory (8-bit enumeration)	Specific (8-bit enumeration)	Extra (8-bit enumeration)
Entity Linear Velocity	X-Component (32-bit floating point)			
	Y-Component (32-bit floating point)			
	Z-Component (32-bit floating point)			
Entity Location	X-Component (64-bit floating point)			
	Y-Component (64-bit floating point)			
	Z-Component (64-bit floating point)			
Entity Orientation	PSI (32-bit floating point)			
	Theta (32-bit floating point)			
	Phi (32-bit floating point)			
Entity Appearance	Entity Appearance (32-bit floating point)			
Dead Reckoning Parameters	Dead Reckoning Algo. (8 bit Enum.)	Other Parameters (120 bits unused)		
	Entity Linear Acceleration (3x32 bit floating points)			
	Entity Angular Acceleration (3x32 bit integers)			
Entity Marking	Character Set (8-bit Enumeration)	11 - 8 bit unsigned integers		
Capabilities	32 Boolean Fields			
Articulation Parameters (for each Articulation Parameter)	Change (16-bit unsigned integer)		ID attached to 16-bit unsigned integer	
	Parameter Type (32-bit parameter type record)			
	Parameter Value 64 bit			

6.3.1.1 Special Modifications for TRACE

6.3.1.1.1 Modifications for TRACE IR Data

In order to satisfy the needs of the Dasa medium range missile and the IR missile several modifications were made to AFRL's standard DIS interface.

6.3.1.2 Medium Range Missile Seeker Head Information

An Electromagnetic Emission PDU with a frequency of 33 Hz was sent when the status of the medium range missiles seeker head changed from guided to autonomous.

6.3.1.3 Fuel Flow and Throttle Position

An Electromagnetic Emission PDU with a frequency of 22 Hz containing the throttle position and fuel flow was sent when the throttle position changed or the fuel flow's most significant 6 bits changed.

6.3.1.4 Dasa Missile Number

The Dasa NICs required knowledge of the missile number from the AFRL missiles. This number was encoded in the Extra field of the Entity Type sent in the Fire PDU.

6.3.1.5 Dasa Missile Status and Break Condition

The missiles endgame status and break condition was encoded into the Detonation PDUs result field instead of using the standard result codes.

6.3.1.6 Radar PDUs

Electromagnetic Emission PDUs were sent out once per second for active radars. Each radar would send one PDU for each aircraft that it painted. Table 6-2 outlines how the Electromagnetic Emissions PDU fields are filled. The radar frequency and beam strength were the average over the previous second of operation.

Field Size (bits)	Electromagnetic Emissions PDU Fields		Data
96	PDU Header	Protocol Version—8-bit enumeration	VR-Link fills
		Exercise ID—8-bit unsigned integer	VR-Link fills
		PDU Type—8-bit enumeration	VR-Link fills
		Protocol Family—	VR-Link fills
		Time Stamp—32-bit unsigned integer	VR-Link fills
		Length—16-bit unsigned integer	VR-Link fills
		Padding—16 bits unused	VR-Link fills
48	Emitting Entity ID	Site—16-bit unsigned integer	AFRL site id
		Application—16-bit unsigned integer	AFRL missile application id
		Entity—16-bit unsigned integer	AFRL missile id
48	Event ID	Site—16-bit unsigned integer	VR-Link fills
		Application—16-bit unsigned integer	VR-Link fills
		Event—16-bit unsigned integer	VR-Link fills
8	Request ID	8-bit enumeration	VR-Link fills
8	Number of Systems (N)	8-bit unsigned integer	1
32	Padding	32 bits unused	0
Varies •	System Data Length	8-bit unsigned integer	VR-Link fills
	Number of Beams (M)	8-bit unsigned integer	1
	Padding	16 bits unused	
	Emitter System	Emitter Name—16-bit enumeration	Radar type
		Function—8-bit enumeration	Radar mode
		Emitter ID Number—8-bit unsigned integer	
	Location in Entity Coordinates	x-Component—32-bit floating point	0.0
		y-Component—32-bit floating point	0.0
		z-Component—32-bit floating point	0.0
	Beam Data Length	8-bit unsigned integer	VR-Link fills
	Beam ID Number	8-bit unsigned integer	1
	Beam Parameter Index	16-bit unsigned integer	
	Fundamental Parameter Data	Frequency—32-bit floating point	Radar frequency
		Frequency Range—32-bit floating point	0.0
		ERP—32-bit floating point	Beam strength
		PRF—32-bit floating point	0.0
		Pulse Width—32-bit floating point	0.0
		Beam Azimuth Center—32-bit floating point	Beam azimuth
		Beam Azimuth Sweep—32-bit floating point	0.0
		Beam Elevation Center—32-bit floating point	Beam elevation
		Beam Elevation Sweep—32-bit floating point	0.0
		Beam Sweep SYNC—32-bit floating point	0.0
	Beam Function	8-bit enumeration	0
	Number of Targets in the Track/Jam Field	8-bit unsigned integer	1
	High Density Track/Jam	8-bit enumeration	0
	Padding	8 bits unused	0
	Jamming Mode Sequence	32-bit unsigned integer	0
	Track/Jam	Site—16-bit unsigned integer	Id of Dasa aircraft painted
		Application—16-bit unsigned integer	Id of Dasa aircraft painted
		Entity—16-bit unsigned integer	Id of Dasa aircraft painted
		Emitter ID—8-bit unsigned integer	0
		Beam ID—8-bit unsigned integer	0

Table 6-2 Emission PDU

6.3.2 DIS-Lite Protocol [AFRL]

6.3.2.1 Background

The DIS-Lite protocol was developed by Mäk Technologies under a Small Business Innovative Research (SBIR) contract. The protocol breaks the Entity State PDU into two new PDUs, the Query Response PDU and the Kinematics PDU. The Query Response PDU will be issued upon creation of an entity or in response to a query from a remove simulation site. This PDU contains the static information in the Entity State PDU. The Kinematics PDU contains the dynamic entity state information. See [Taylor, Darrin Sc. D. "DIS-Lite & Query Protocol", 13th DIS Workshop Proceedings. Paper No.: 95-13-113.] and [Taylor, Darrin, Sc. D. "DIS-Lite & Query Protocol: Message Structures", 14th DIS Workshop Proceedings. Paper No.: 96-14-093.]

Protocol Details The DIS-Lite protocol defines 4 new PDUs: the Query Response PDU (QR-PDU), the Kinematic PDU (KIN-PDU), the Lite Query PDU (LTQ-PDU), and the Simulation Done PDU (SD-PDU). The data contained in the PDUs are delineated below. The next section Darrins paper: Taylor, D. Sc. D., "DIS-Lite & Query Protocol: Message Structures", 14th DIS Workshop, Paper No.: 96-14-093.

6.3.2.1.1 Query Responce PDU

The QR-PDU is the static data from the DIS Entity State PDU (ES-PDU) and are only sent when the entity enters the exercise, when any of the static data changes, when an entity receives an LTQ-PDU, or when recovering from simulator problems. The sequence number is incremented whenever any of the static data changes. This number is also contained in the KIN-PDU which helps maintain consistency of the data. If a KIN-PDU is received that has a sequence number that the receiver has not received, the sender will be queried for a QR-PDU. The Time Out parameter tells the receivers when the sender will send data again and is used instead of the usual DIS heartbeat. Slow moving or stationary entities may wait for long periods before sending out any data. The Group Number represents a set of entities that are competing for bandwidth and the Group Size is the number of entities in the group. Articulated parts are handled the same as in an ES-PDU.

Query Response PDU	
Section	**Size in bits**
DIS PDU Header	96
Queried Entity Identifier	48
Sequence	8
Dead Reckon Algorithm	8
Capabilities	32
Appearance	32
Type	64
Guise	64
Time Out	32
Location	192
Orientation	96
Velocity	96
Angular Velocity	96
Acceleration	96
Marking	96
Force Id	8
Art Part Header	8 = z
Group Number	8
Group Size	8
Art Part Record	z * 128 bits

6.3.2.1.2 Kinematic PDU

The KIN-PDU contains the dynamic data for the entity and are sent when the dead reckon thresholds are exceeded or when any articulated part data changes. The size of this PDU is dependent upon the dead reckoning algorithm currently in effect. A Maximal KIN-PDU contains all the optional fields and a Minimal KIN-PDU contains none of the optional fields. When an entity reaches a threshold time out as it will send a finite number of Maximal KIN-PDUs before smaller KIN-PDUs are sent. The data contained in a KIN-PDU is specified by the Kinematic PDU Enumeration field which is dependent upon the dead reckoning algorithm in effect and which threshold was crossed. The QR-Sequency corrseponds to the sequence number in the last QR-PDU sent. The K-Sequence number is associated with the KIN-PDU and is used in conjunction with the QR-PDU Time Out value.

Kinematic PDU	
Section	**Size in bits**
DIS PDU Header	96
Entity Identifier	48
K-Sequence	8
QR-Sequence	8
Art Part Header Word Count - optional	8 = x
Kinematic PDU Enumeration - optional	8
Unused - optional	16
Location - optional	192
Orientation - optional	96
Velocity - optional	96
Acceleration - optional	96
Angular Velocity - optional	96
Time Out - optional	32
Art Data Header	x * 16 (norm = y)
Art Data Array - optional	y * 32

6.3.2.1.3 Lite Query PDU

The LTQ-PDU is sent when information about an entity is needed. The receiving entity will respond by sending a QR-PDU and a finite number of Maximal KIN-PDUs. The Queried Entity Identifier represents who is being queried. The Sequence Number if positive refers to a request for a QR-PDU with that sequence number and if negative refers to a KIN-PDU with the corresponding positive sequence number.

Lite Query PDU	
Section	**Size in bits**
DIS PDU Header	96
Queried Entity Identifier	48
Sequence Number	8

6.3.2.1.4 Simulation Done PDU

The SD-PDU is sent to inform all the simulations in the exercise that an entity has left the exercise.

Simulation Done PDU	
Section	**Size in bits**
DIS PDU Header	96
Entity Identifier	48

Differences from DIS Standard ES-PDUs are no longer the mechanism to broadcast time critical data. This function has been moved to the KIN-PDU. The QR-PDU and the KIN-PDU work together to keep receivers informed of the state of remote entities. Reliability is maintained through the use of sequence numbers and individual entities time out values instead of the traditional DIS heartbeat. Minimal KIN-PDUs are sent at entity time outs as a heartbeat instead of a full ES-PDU to lower bandwidth usage.

6.3.2.1.5 Query Response PDU

The QR-PDU contains most of the data in an ES-PDU but is not used for time critical data like the Entity State PDU. The sequence number, time out, group number, and group size are not present in an ES-PDU. Also, this PDU can be different sizes depending upon the dead reckoning algorithm that is in effect, but it is still smaller that an ES-PDU.

6.3.2.1.6 Kinematic PDU

The KIN-PDU contains an augmented subset of the data contained in an ES-PDU. Articulated parts are handled differently and more efficiently than in an ES-PDU.

6.3.2.1.7 Lite Query PDU

DIS does not have an equivalent PDU.

6.3.2.1.8 Simulation Done PDU

In a normal DIS exercise, simulations are notified of entities leaving by the final bit being set in an ES-PDU's appearance bits or by the entity timing out.

6.3.3 Dasa Protocol [Dasa]

6.3.3.1 Background

The Dasa Protocol was developed in a national technology study project called "Verbundene Luftkriegs Operation (VLO)". The VLO project started in 1992. The goal was to develop an optimized protocol for use in air combat simulation applications.

6.3.3.2 Protocol Details

The Dasa Protocol comprises 9 Protocol Data Units (PDU's). For simulation management, the available PDU's are:

- Command PDU
- Data Exchange PDU

and for data transfer during simulation operation the available PDU's are:

- Entity Appearance PDU
- Complex Dead Reckoning PDU
- Simple Dead Reckoning PDU
- Radar PDU
- Jammer PDU
- Flare PDU
- Chaff PDU

The PDU's are delineated in the following chapters.

6.3.3.2.1 Command PDU

The Command PDU is used for sending simulation management commands to the participants of an simulation exercise.

The command field contains commands like Start, Stop, Initialize.

The effect time denotes the time when the command is valid.

COMMAND PDU		
Sender ID	site	uint8
	application	uint8
	pdu type = 1	uint8
Sender ID	entity	uint8
Receiver ID	site	uint8
	application	uint8
	entity	uint8
	command ID	uint8
	effect time	uint32

total 96 bits (12 bytes)

Fig. 6-6 Command PDU

6.3.3.2.2 Data Exchange PDU

The Data Exchange PDU is mainly used for data transfer from or to the Simulation Manager. The contents field describes the contents of the data fields.

DATA EXCHANGE PDU		
Sender ID	site	uint8
	application	uint8
	pdu type = 2	uint8
Sender ID	entity	uint8
Receiver ID	site	uint8
	application	uint8
	entity	uint8
	contents	uint8
	the data	52 bytes

total 480 bits (60 bytes)

Fig. 6-7 Data Exchange PDU

6.3.3.2.3 Entity Appearance PDU

This PDU contains the status, the appearance and other data of an entity which are changing slowly or aren't changing at all during the lifecycle of an entity.

The entity type specifies the superior type like aircraft, missile, etc. The subtype provides more precise information about the given entity type. The status field communicates the status of an entity such as active, missile in flight, or missile hit, etc. The force number tells the side (blue, red, neutral) the entity belongs to.

The appearance field contains data like gear state, afterburner state, IFF, infrared information etc.

ENTITY APPEARANCE PDU		
Entity ID	site	uint8
	application	uint8
	pdu type = 10	uint8
Entity ID	entity	uint8
	entity type	uint8
	subtype	uint8
	status	uint8
	force number	uint8
	appearance	20 bytes
	spares	4 bytes

total 256 bits (32 bytes)

Fig. 6-8 Entity Appearance PDU

6.3.3.2.4 Complex Dead Reckoning PDU

The Complex Dead Reckoning PDU comprises all kinematics data of an entity. The time stamp identifies when the data is valid.

The LSB of the Position fields is 0.01 m.

The LSB of the Velocity fields is 0.1 m/sec.

The LSB of the Acceleration fields is 0.1 m/sec2.

The orientation of the entity is given in quaternions.

The LSB of the Orientation fields are 1/(215 - 1).

The LSB of the Orientation Rates fields are 0.001 rad/sec.

The LSB of the Orientation Acceleration fields are 0.01 rad/sec2.

COMPLEX DEAD RECKONING PDU		
Entity ID	site	uint8
	application	uint8
	pdu type = 11	uint8
Entity ID	entity	uint8
	time stamp	uint32
Position	x	int32
	y	int32
	z	int32
Velocity	Vx	int16
	Vy	int16
	Vz	int16
Acceleration	Ax	int16
	Ay	int16
	Az	int16
Orientation	q0	int16
	q1	int16
	q2	int16
	q3	int16
Orientation Rates	p	int16
	q	int16
	r	int16
Orientation Acceleration	pp	int16
	pq	int16
	pr	int16

total 416 bits (52 bytes)

Fig. 6-9 Complex Dead Reckoning PDU

6.3.3.2.5 Simple Dead Reckoning PDU

The Simple Dead Reckoning PDU is a streamlined form of the Complex Dead Reckoning PDU, optimized for the needs of missile entities. The missile orientation is calculated from the extrapolated velocity vector. The precision of the orientation achieved by this method is sufficient for missiles.

SIMPLE DEAD RECKONING PDU		
Entity ID	site	uint8
	application	uint8
	pdu type = 12	uint8
Entity ID	entity	uint8
	time stamp	uint32
Position	x	int32
	y	int32
	z	int32
Velocity	Vx	int16
	Vy	int16
	Vz	int16
	spare	int16

total 416 bits (52 bytes)

Fig. 6-10 Simple Dead Reckoning PDU

6.3.3.2.6 Radar PDU

The Radar PDU contains information about the use of radar emitters for stimulation of radar warning receivers, or radar detection systems. The position of the emitter can be obtained via the Sender ID. The Receiver ID contains the entity ID of the receiver entity.

The radar mode field communicates the status of the emitter, e.g. not active, search, track.

The radar system type is specified in the radar type field.

The LSB of the frequency is 1 MHz.

The beam direction/elevation contains the azimuth/elevation angle as seen from the target.
The LSB is 0.001 rad.

The beam strength field indicates the power in dB with reference to 1 Watt/m2 at the target.
The LSB is 0.1 dB.

RADAR PDU		
Sender ID	site	uint8
	application	uint8
	pdu type = 22	uint8
Sender ID	entity	uint8
Receiver ID	site	uint8
	application	uint8
	entity	uint8
	radar mode	uint8
	radar type	uint16
	frequency	uint16
	beam direction	int16
	beam elevation	int16
	beam strength	int16
	spare	int16

total 160 bits (20 bytes)

Fig. 6-11 Radar PDU

6.3.3.2.7 Jammer PDU

The Jammer PDU contains information about the use of a jammer for jamming radar, radar warning receivers, or radar detection systems. The position of the jammer can be obtained via the Sender ID. The Receiver ID contains the entity ID of the receiver entity.

The jammer mode field communicates the status of the jammer, e.g. active, not active.

The type of the jammer is specified in the jammer type field.

The LSB of the frequency is 1 MHz.

The heading/elevation to jammer field contains the azimuth/elevation angle as seen from the target.

The LSB is 0.001 rad.

The signal strength field indicates the power in dB with reference to 1 Watt/m2 at the target.

The LSB is 0.1 dB.

JAMMER PDU		
Sender ID	site	uint8
	application	uint8
	pdu type = 33	uint8
Sender ID	entity	uint8
Receiver ID	site	uint8
	application	uint8
	entity	uint8
	jammer mode	uint8
	jammer type	uint16
	frequency	uint16
	heading to jammer	int16
	elevation to jammer	int16
	signal strength	int16
	spare	int16

total 160 bits (20 bytes)

Fig. 6-12 Jammer PDU

6.3.3.2.8 Flare PDU

The Flare PDU contains information about a flare bundle thrown out to mislead infrared guided seeker heads.

FLARE PDU		
Sender ID	site	uint8
	application	uint8
	pdu type = 31	uint8
Sender ID	entity	uint8
	timestamp	uint32
	active flag	int32
	entity type = 2000	int32
	launcher ID	uint32
	number of flares	int16
	flare type	int16
	ignition delay	int16
	light intensity number	int16

total 224 bits (28 bytes)

Fig. 6-13 Flare PDU

6.3.3.2.9 Chaff PDU

The Chaff PDU contains information about a chaff bundle thrown out to mislead radar guided seeker heads.

	CHAFF PDU	
Sender ID	site	uint8
	application	uint8
	pdu type = 32	uint8
Sender ID	entity	uint8
	timestamp	uint32
	active flag	int32
	entity type = 3000	int32
	launcher ID	uint32
	number of chaffs	int16
	aspect ratio	int16
	wing area	int8
	wing span	int8
	air mass	int16

total 224 bits (28 bytes)

Fig. 6-14 Chaff PDU

6.3.3.3 Differences from DIS Standard

Comparing the Dasa Protocol with the DIS Protocol the following essential differences can be observed:

- the Dasa Protocol subdivides the description of an entity into a high frequency changing kinematics part (Complex/Simple Dead Reckoning PDU 52/28 bytes) and into a low frequency changing appearance part (Entity Appearance PDU 32 bytes) whereas in DIS with every position update the whole entity description (Entity State PDU 144 bytes minimum) must be transferred. By not transferring unnecessary (redundant) data, less bandwidth is required by the Dasa protocol.
- the Dasa Protocol uses a second order extrapolation algorithm for orientation extrapolation whereas DIS only uses a first order extrapolation algorithm. The orientation extrapolation improvement results in reduced update rates and thus a reduced bandwidth requirement. This characteristic proved to be very effective especially during highly dynamic maneuvers such as dog fights in air combat scenarios.
- in the Dasa Protocol a special streamlined PDU for the kinematics missile data update (Simple Dead Reckoning PDU 28 bytes) saves network bandwidth, especially in the bandwidth consuming engagement phase of a complex air combat scenario.
- the Dasa Protocol is more streamlined than the DIS Protocol. For example, DIS requires 24 bytes to specify position while the Dasa protocol requires only 12 bytes. The Dead Reckoning Parameter field in the DIS Entity State PDU contains 15 bytes of unused data.
- to communicate, for example, a landing gear state change requires the transfer of an Entity Appearance PDU (length 32 Bytes) when running the Dasa Protocol. In DIS, 160 bytes are needed (Entity State PDU with one Articulation Parameter) for this information.
- Flares and Chaff simulation in DIS would require an Entity State PDU (144 bytes) for each flare/chaff in the bundle. In the Dasa Protocol, 28 bytes are needed for the whole flare or chaff bundle.

- all Dasa PDU's are of fixed length and therefore easy to decode. In DIS, many PDU's are variable in size and can become very unhandy when being decoded, especially the Emission PDU.

DIS 2.0.4/DIS-Lite		Dasa	
Ethernet Header	*First 22 bytes*	*Ethernet Header*	*First 22 bytes*
IP Header	*Next 20 bytes*	*IP Header*	*Next 20 bytes*
UDP Header	*Next 8 bytes*	*UDP Header*	*Next 8 bytes*
PDU Header		Dasa Header	
Protocol Version	1 byte (4)	Dasa site	1 byte (0b = Germany, 0c = US)
Exercise ID	1 byte	Dasa Application	1 byte
PDU Type	1 byte (1-27 DIS, 28-31 DIS-Lite)	Dasa Type	1 byte (1,2,10,11,12,20,21)
Padding	1 byte	Dasa Entity	1 byte
Remaining Fields	Same as usual/varies by type	Remaining Fields	Same as usual/varies by type

Table 6-3: DIS/DIS-Lite/Dasa Comparisons

6.4 Networking Experiments [Dasa & AFRL]

6.4.1 Evaluation of the transfer-media [Dasa]

The following transfer media were used for the transatlantic network

⇨ Standard ISDN-telephone line

⇨ DSI (connected via ISDN)

For the evaluation of the media, Dasa took measurements with simple tools to determine technical data such as usable bandwidth and media specific delay times.

	DSI-Connection	ISDN- Connection
Usable Bandwidth	60-70 kBit/sec	> 100 kBit/sec
Delay Times	150-180 msec	80 -100msec
costs	$7700/month + ISDN (Stuttgart)	1,44DM/min
Support	-	N/A
Availability	--	++
Response Time	-	++

Table 6-4 Media Cost

Houston Associates Incorporated, the operator of the DSI, could not explain why the DSI performance was so bad. It is possible that the non-standard means by which Dasa connected to the DSI (dial-up ISDN line between Dasa and Stuttgart) may attribute to its poor performance. The normal connection has a T-1 line (1.55 Mbit/sec)

between the user and DSI hub. A more detailed analysis is not possible without the help of the supplier since Dasa AND VACD had no information about the modifications and systems used including the ISDN terminal adapter installed at the DASA laboratories.

The fixed cost for the DSI was $7700/month plus $2500 for installation. The costs of the ISDN telephone connection to Stuttgart must be added. This ISDN line had to be set up at least one hour in advance of DSI usage and must not be disconnected during the run to ensure proper functionality.

The support was slow and the connection could only be set up on request of AFRL since the DSI was an experimental network being developed by the US government to support networked simulations.

6.4.2 Preliminary Network Delay Tests [AFRL]

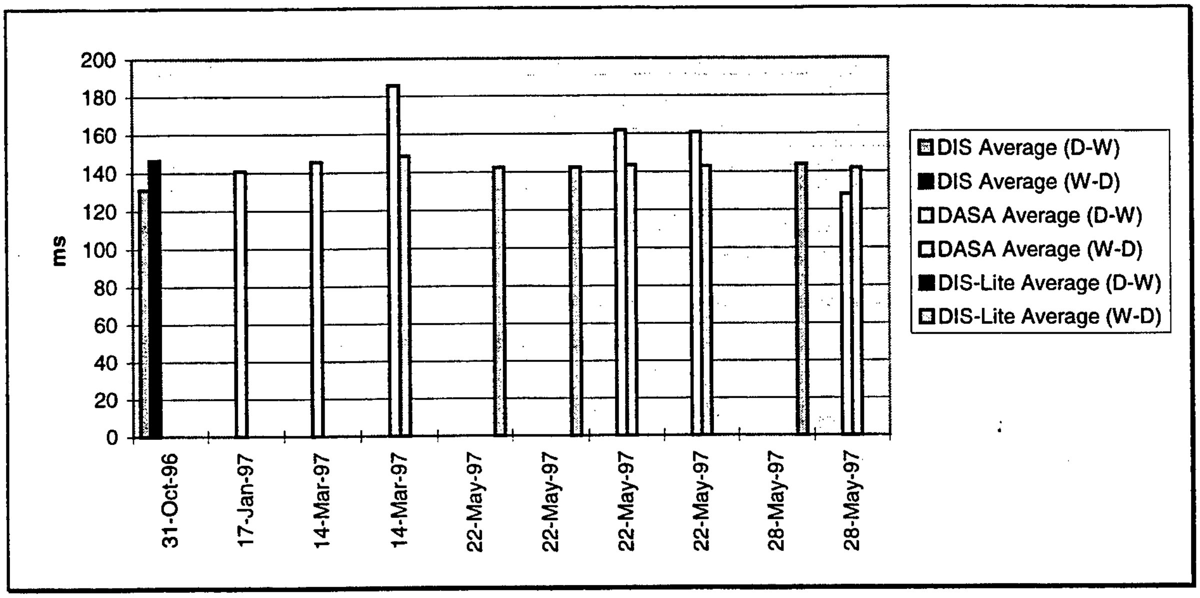


Fig. 6-15 DSI Network Delays

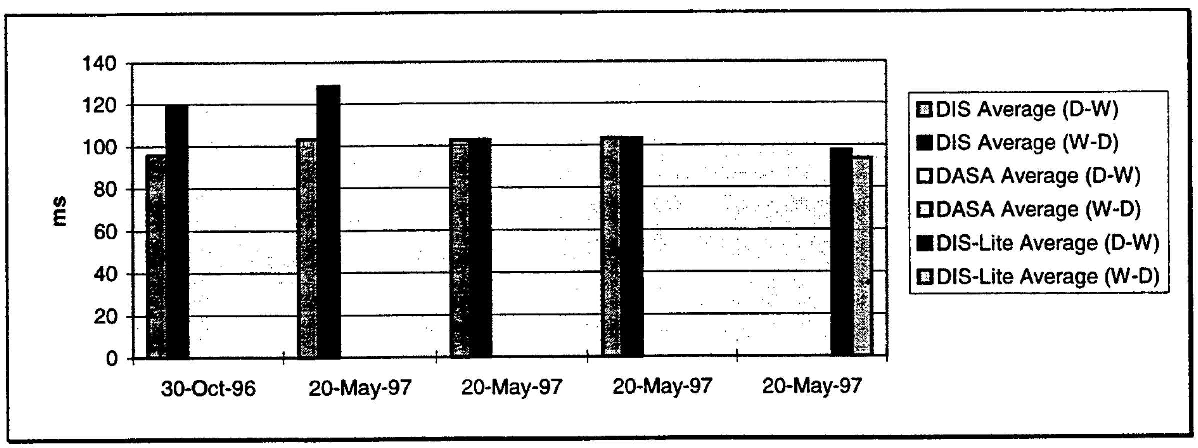


Fig. 6-16 ISDN Network Delays

6.4.3 End-to-End Tests [AFRL]

Two types of end-to-end tests were performed using SNAP. The first was simply a network transit delay. In this test SNAP time-stamped all transmitted and received PDU traffic. This time-stamped data could then be analyzed to determine network transit delays and to some degree bandwidth requirements.

The second test was a complete end-to-end test. This test required SNAP to input a signal to one of the two site's simulators. SNAP with EVDAS would then sample/record and time-stamp, using GPS time, data at various points along the simulation process. Data was taken at the stick input, SCRAMNet for state variable data at both sites, visual output at both sites, and at the input from the ISDN router (LAN) side at both sites. This recorded and time-stamped data could then be analyzed to give the amount of time it takes for a simulation to process data. The results of these tests are presented below.

Dasa protocol	*Dasa driving stick*			
	max	average	median	min
$Stick_{GE}$-$Roll_{GE}$	0.054	0.045	0.050	0.021
$Stick_{GE}$-$EVDAS_{GE}$	0.370	0.193	0.189	0.120
$Stick_{GE}$-PDU_{GE}	0.301	0.140	0.145	0.044
$Stick_{GE}$-PDU_{US}	0.394	0.231	0.239	0.039
$Stick_{GE}$-$Roll_{US}$	0.374	0.269	0.276	0.178
$Stick_{GE}$-$EVDAS_{US}$	0.508	0.400	0.407	0.311
Network $Transport_{GE\ to\ US}$	0.134	0.098	0.094	0.093

Dasa protocol	*AFRL driving Stick*			
	max	average	median	min
$Stick_{US}$-$Roll_{US}$	0.067	0.058	0.058	0.050
$Stick_{US}$-$EVDAS_{US}$	0.233	0.205	0.208	0.183
$Stick_{US}$-PDU_{US}	0.205	0.156	0.162	0.077
$Stick_{US}$-PDU_{GE}	0.302	0.255	0.261	0.175
$Stick_{US}$-$Roll_{GE}$	0.329	0.274	0.277	0.191
$Stick_{US}$-$EVDAS_{GE}$	0.408	0.359	0.359	0.288
Network $Transport_{US\ to\ GE}$	0.101	0.099	0.098	0.098

DIS Protocol	*Dasa Driving Stick*			
	max	average	median	min
$Stick_{GE}$-Roll $Rate_{GE}$	0.051	0.031	0.025	0.022
$Stick_{GE}$-$EVDAS_{GE}$				
$Stick_{GE}$-PDU_{GE}	0.251	0.189	0.189	0.109
$Stick_{GE}$-PDU_{US}	0.188	0.128	0.136	0.033
$Stick_{GE}$-$Roll_{US}$	0.295	0.235	0.242	0.139
$Stick_{GE}$-$EVDAS_{US}$	0.333	0.264	0.280	0.106
Network $Transport_{GE\ to\ US}$	0.294	0.294	0.294	0.294

DIS Protocol	*AFRL driving stick*			
	max	average	median	min
$Stick_{US}$-Roll $Rate_{US}$	0.083	0.060	0.067	0.033
$Stick_{US}$-$EVDAS_{US}$	0.250	0.204	0.200	0.167
$Stick_{US}$-PDU_{US}	1.998	0.167	0.087	0.037
$Stick_{US}$-PDU_{GE}	0.346	0.210	0.200	0.137
$Stick_{US}$-$Roll_{GE}$	0.390	0.248	0.226	0.172
$Stick_{US}$-$EVDAS_{GE}$	0.415	0.329	0.320	0.260
Network $Transport_{US\ to\ GE}$	0.116	0.104	0.100	0.100
PDU_{GE} - $EVDAS_{GE}$	0.227	0.119	0.117	0.020

DIS-Lite Protocol	*Dasa driving stick*			
	max	average	median	min
$Stick_{GE}$-Roll $Rate_{GE}$	0.051	0.040	0.050	0.022
$Stick_{GE}$-$EVDAS_{GE}$	0.986	0.188	0.145	0.098
$Stick_{GE}$-PDU_{GE}				
$Stick_{GE}$-PDU_{US}				
$Stick_{GE}$-$Roll_{US}$	0.208	0.142	0.138	0.104
$Stick_{GE}$-$EVDAS_{US}$	0.613	0.350	0.314	0.185
Network $Transport_{GE\ to\ US}$				

DIS-Lite Protocol	*AFRL driving stick*			
	max	average	median	min
$Stick_{US}$-Roll $Rate_{US}$	0.067	0.063	0.067	0.050
$Stick_{US}$-$EVDAS_{US}$	0.233	0.195	0.200	0.133
$Stick_{US}$-PDU_{US}				
$Stick_{US}$-PDU_{GE}				
$Stick_{US}$-$Roll_{GE}$	0.297	0.271	0.275	0.231
$Stick_{US}$-$EVDAS_{GE}$	0.398	0.346	0.347	0.290
Network $Transport_{US\ to\ GE}$				

The analysis of this data is at times very subjective. SNAP saves the data in tab deliminated text form. To analyze it it is imported into Excel and plotted. Changes in the plots show where the variables change. If the data plots are noisy, little to no information is available . Where possible a best judgement call was made to determine at what point the state changed. Sample plots of SNAP data are shown below. In all instances the X label indicates the GPS timestamp for each data point.

Figure 6-17 shows one example of the graphs used to determine the time at which the stick input, the roll state variable and the roll rate state variable changed. The labeled points indicate, for this run, the points chosen.

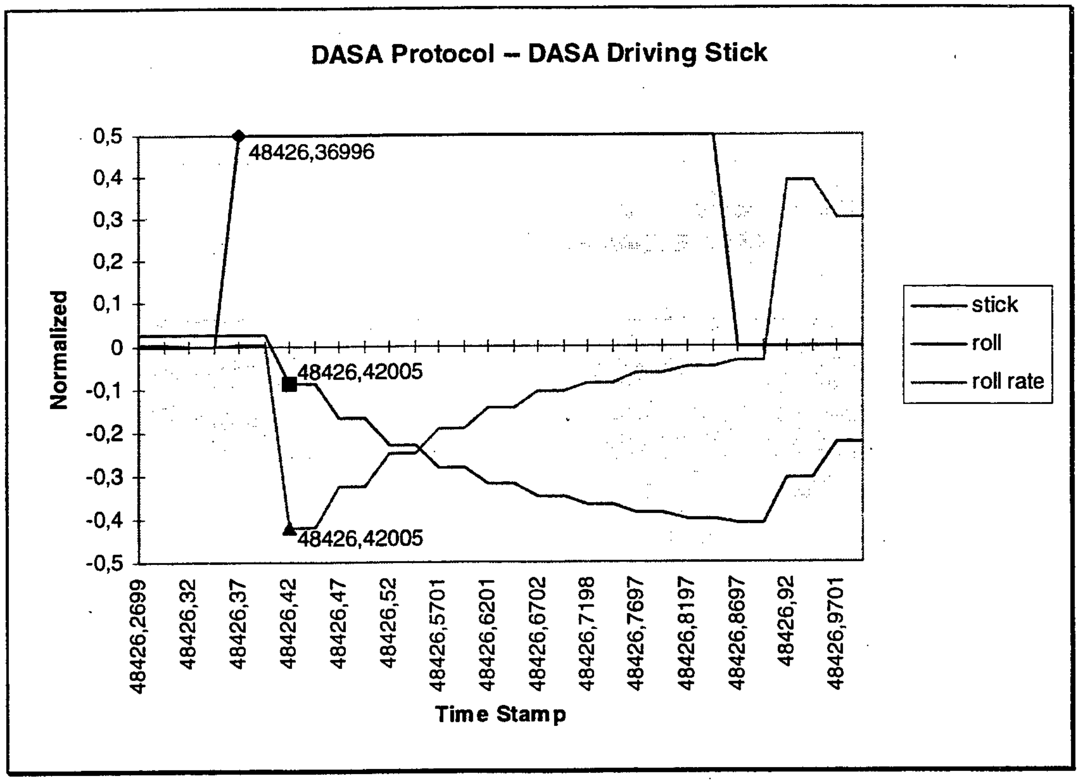


Fig. 6-17 Dasa: Dasa Driving Stick

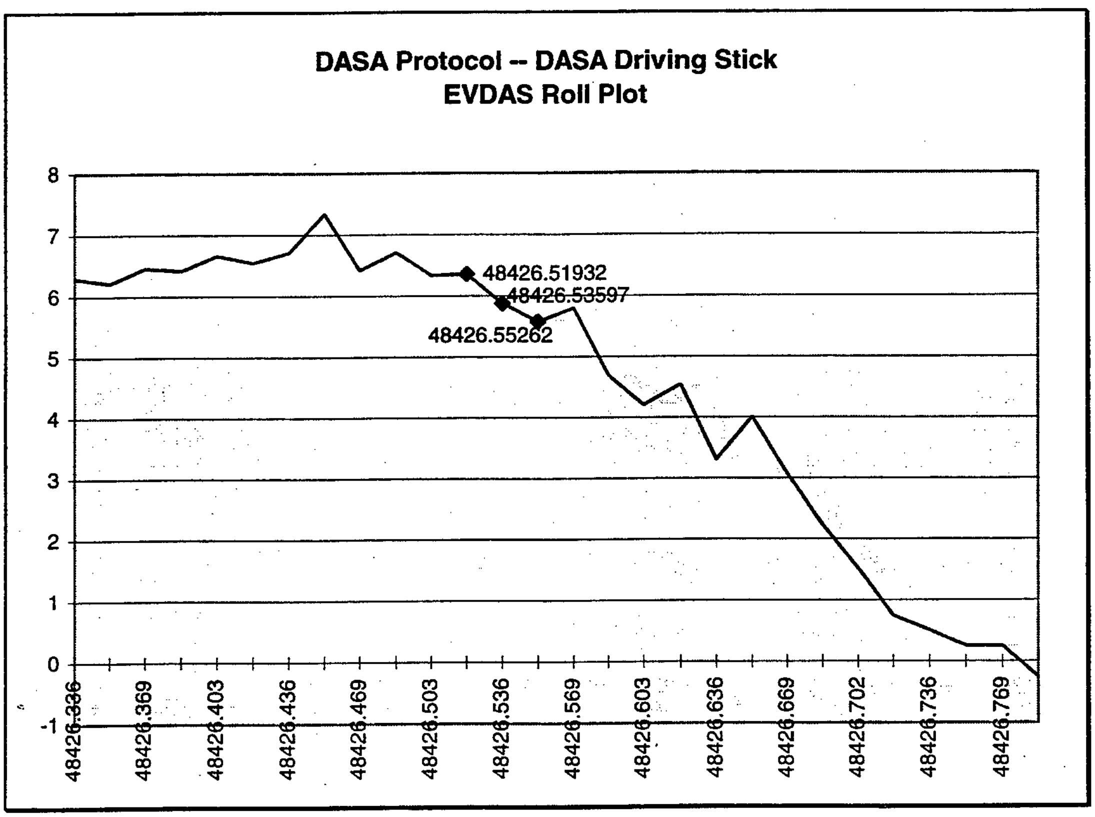


Fig. 6-18 Dasa: Dasa Driving Stick

Figure 6-18 again shows an example of the type of graph used to determine the point at which the pilots visual display would indicate a change in his attitude. The three labelled points indicate that the point was not easily chosen. For this run, the point with the timestamp label of 48426.53597 was chosen.

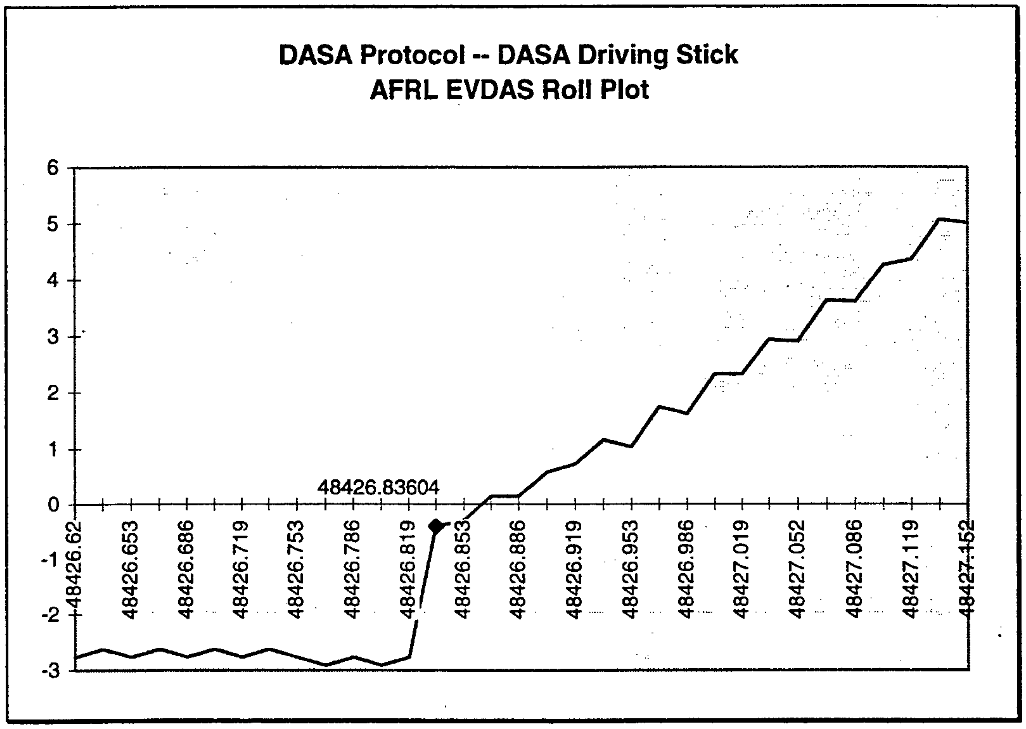


Fig. 6-19 Dasa: AFRL EVDAS Roll Plot

Figure 6-19 shows another example of the type of graph used to determine when the pilots visual display changed, showing the Dasa aircrafts attitude change on the AFRL simulation's visual display. This plot and figure 6-18 both come from data collected from EVDAS.

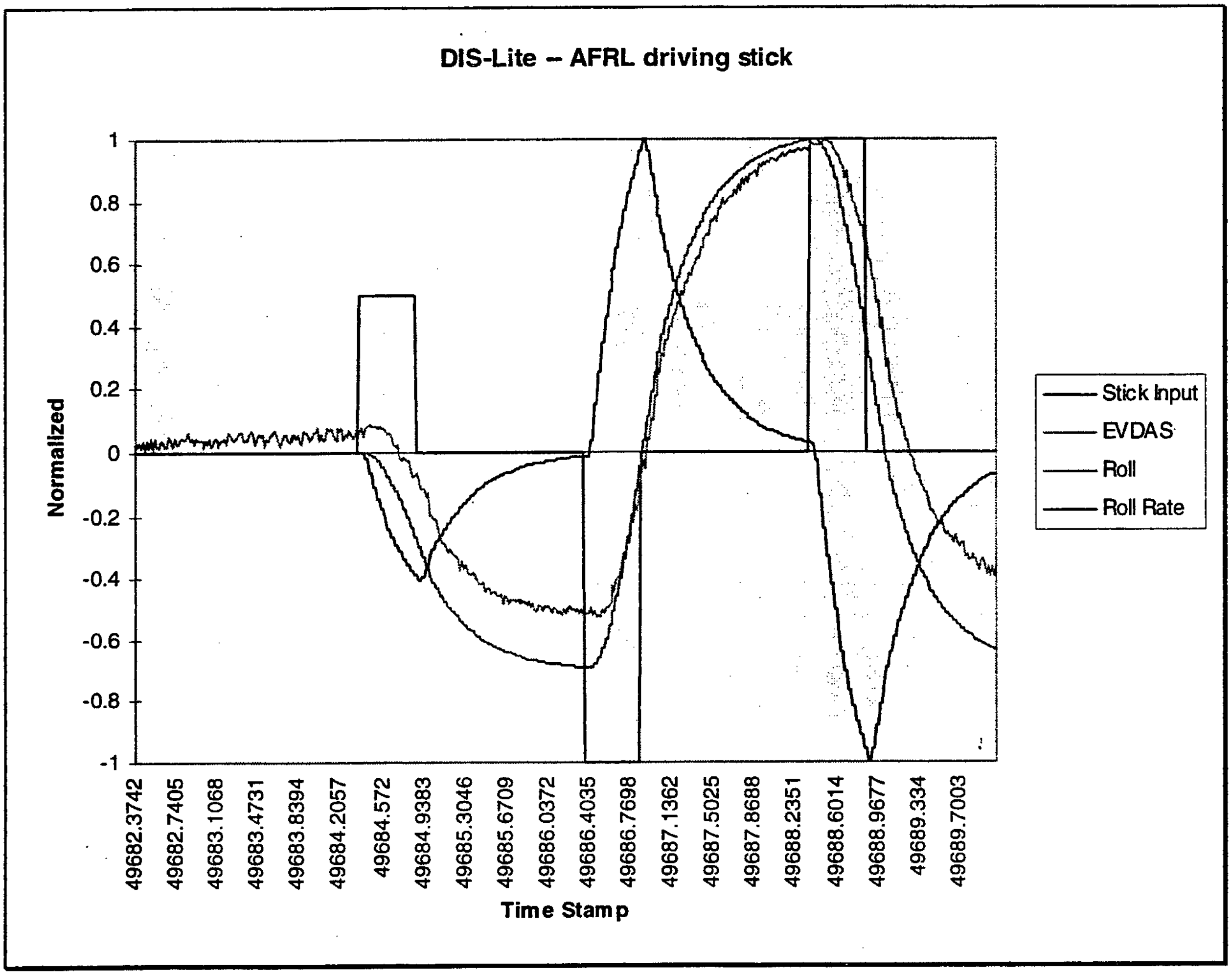


Fig. 6-20 DIS-Lite: AFRL Driving Stick

Figure 6-20 shows a time correlated, combined plot of the stick input, EVDAS (visual system changes), and the roll and roll rate state variabe changes. This better shows the result of a single SNAP run. The stick signal is input to the simulator by SNAP. This is followed by a roll and roll rate change which is followed by a visual system change (EVDAS). The plot graphically shows the delay between each reaction to the stick input signal.

Figures 6-21 shows an example graph used to determine when the Dasa simulation showed the attitude change for the AFRL aircraft.

Figure 6-22 shows an example of the graphs used to determine when the roll rate for the AFRL aircraft was updated in the Dasa simulation.

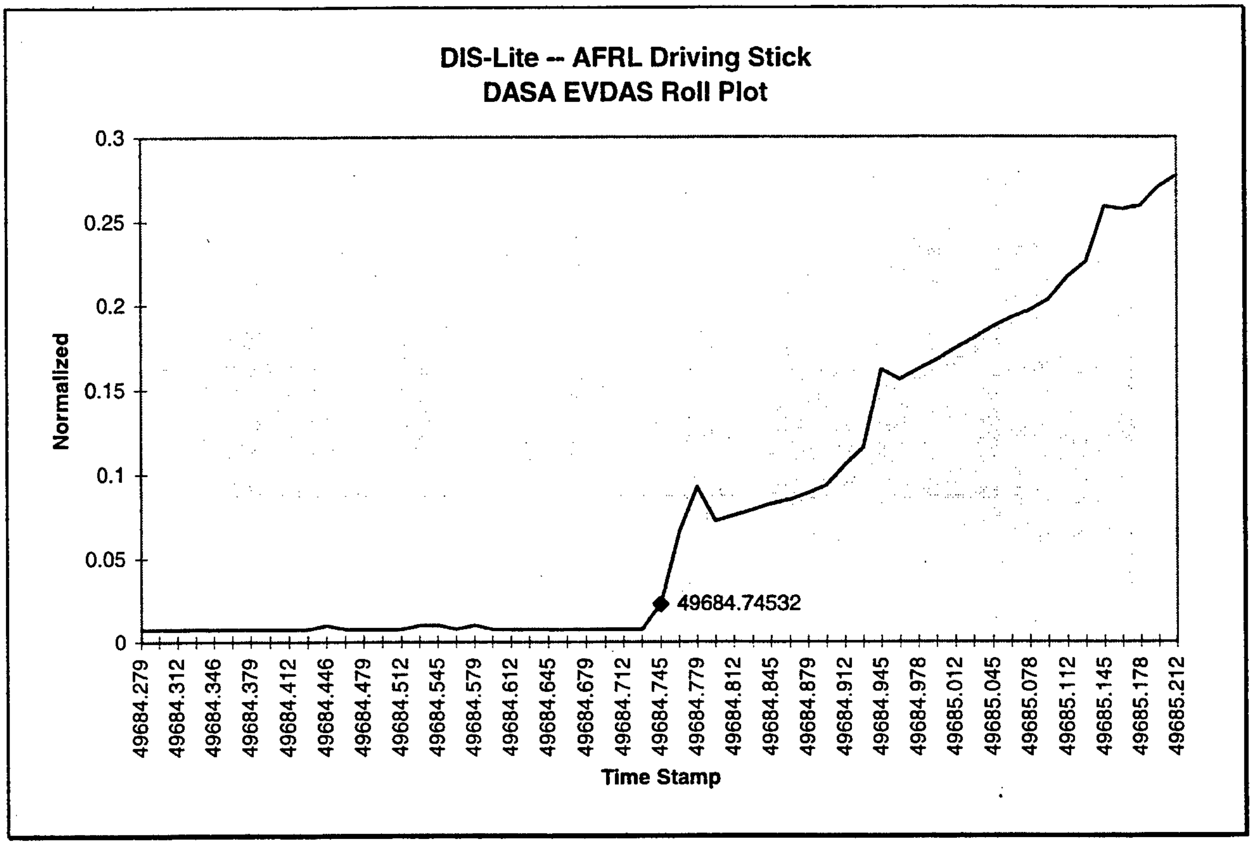


Fig. 6-21 DIS-Lite: Dasa EVDAS Roll Plot

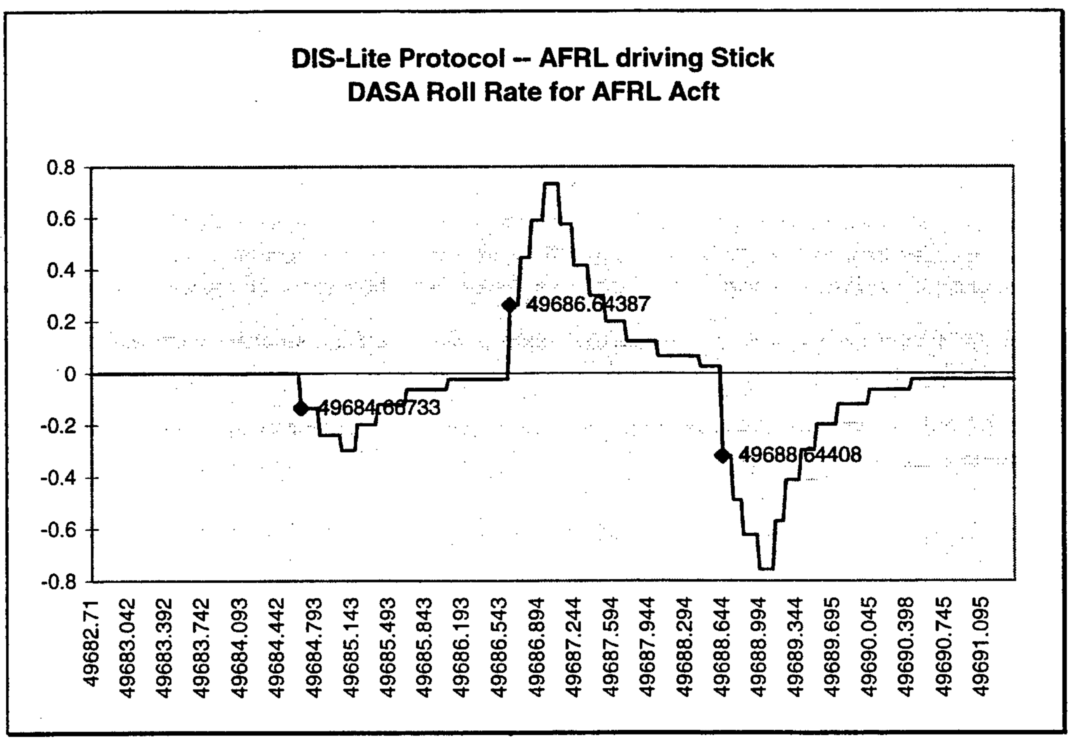


Fig. 6-22 DIS-Lite: AFRL Driving Stick / Dasa Roll Rate

6.4.4 Head-to-Head comparison of the DIS- and Dasa-Protocol [Dasa]

The two protocols primarily used for simulator networking in the TRACE program were the DIS- and the Dasa protocols. In addition to the subjective evaluation of experienced pilots, the end user, an objective evaluation of the system and performance data should be done. In this chapter, a head-to-head comparison was done by measuring the position and flight angle error of a transferred aircraft using simple but directly comparable flight maneuvers.

6.4.4.1 The Test Configuration

A flight path was recorded, which could be replayed several times under different test configurations and conditions. The data recorder had access to the DASA simulator's NIC interface and all changes in data belonging to the simulated aircraft were time stamped and recorded.

For the measurements, the data recorder played the data back to the simulator's NIC-interface which simulates a connected simulated aircraft for the NIC.

Since the measurements lasted for several days, influences of external media (such as ISDN) were excluded by using local Ethernet connections. For control reasons a complete simulator was connected to the receiving NIC and the replayed aircraft was displayed on the visual system. It was verified that the connected simulator had no influence on the measured data. The data recorder again has access to the simulator's NIC interface and recorded the transferred aircraft's changing data together with a time stamp. The synchronization of the time base was done by using the time signal from the GPS (Global Positioning System), as it is done for the WAN-connection.

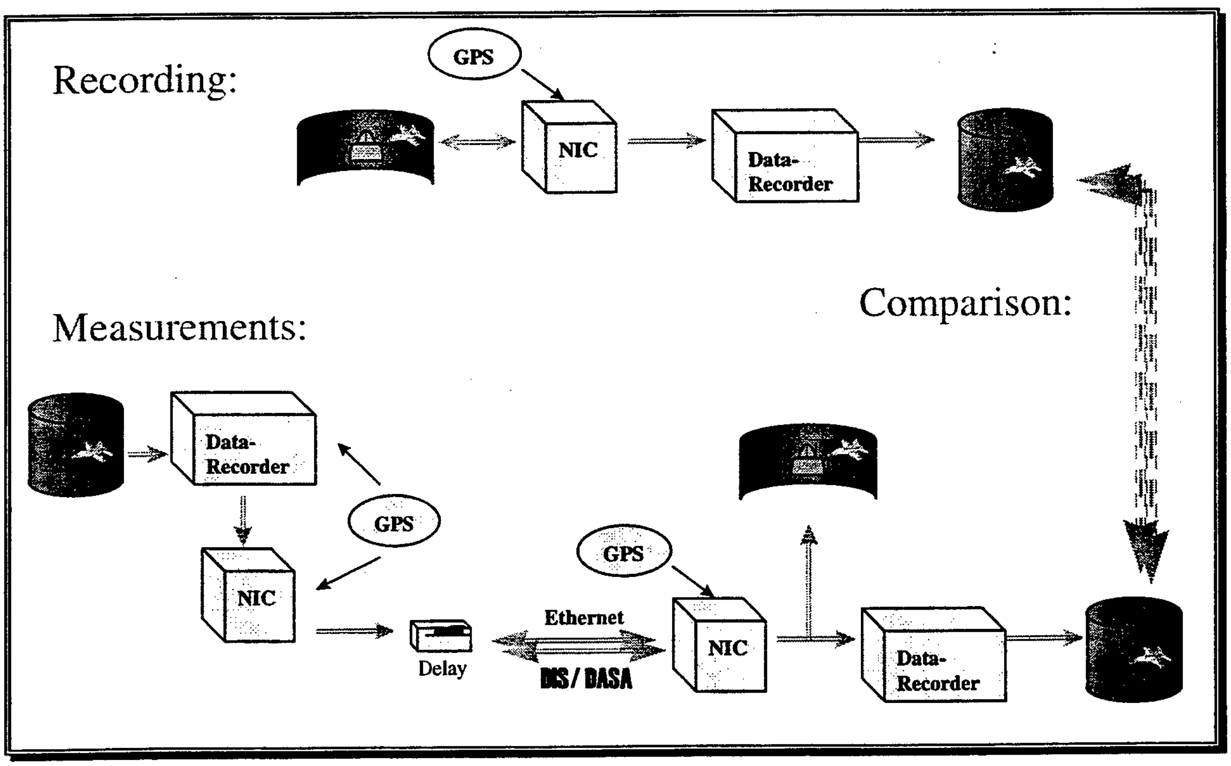


Fig. 6-23 Test Configuration

The influences of the delay times as a result of the transatlantic distances were simulated by a delay tool, which enables arbitrary delay times (distances) to be produced. Because such a tool needs processing time and therefore influences itself too, it was always integrated in the test configuration.

The following tests were performed

- no extrapolation at the receiving site, 0msec delay time
  => these data sets are recognizable and were really transmitted and represent the basis for the extrapolation to the original flight path.
- with extrapolation at the receiving site, 0msec delay time
  from which the quality of the extrapolation to the original flight path can be recognized
- with extrapolation at the receiving site, 100msec delay time
  from which the influence on the distance caused by the delay time can be recognized
- all measurements were performed with both the DIS- and Dasa-Protocol
  from which the differences using the protocols become visible.

The recorded data sets were transformed into ASCII text files and imported into MS-EXCEL for analysis.

6.4.4.2 Data Regeneration

The referencing flight path consists of a normal and a hard right and left turn. This flight maneuver shows how the different rates of acceleration or change in target speed, angle or position influence the procedure used for transmission. The following graph shows the X- and Phi-values (position and attitude). The results can be reflected on all coordinates and angles.

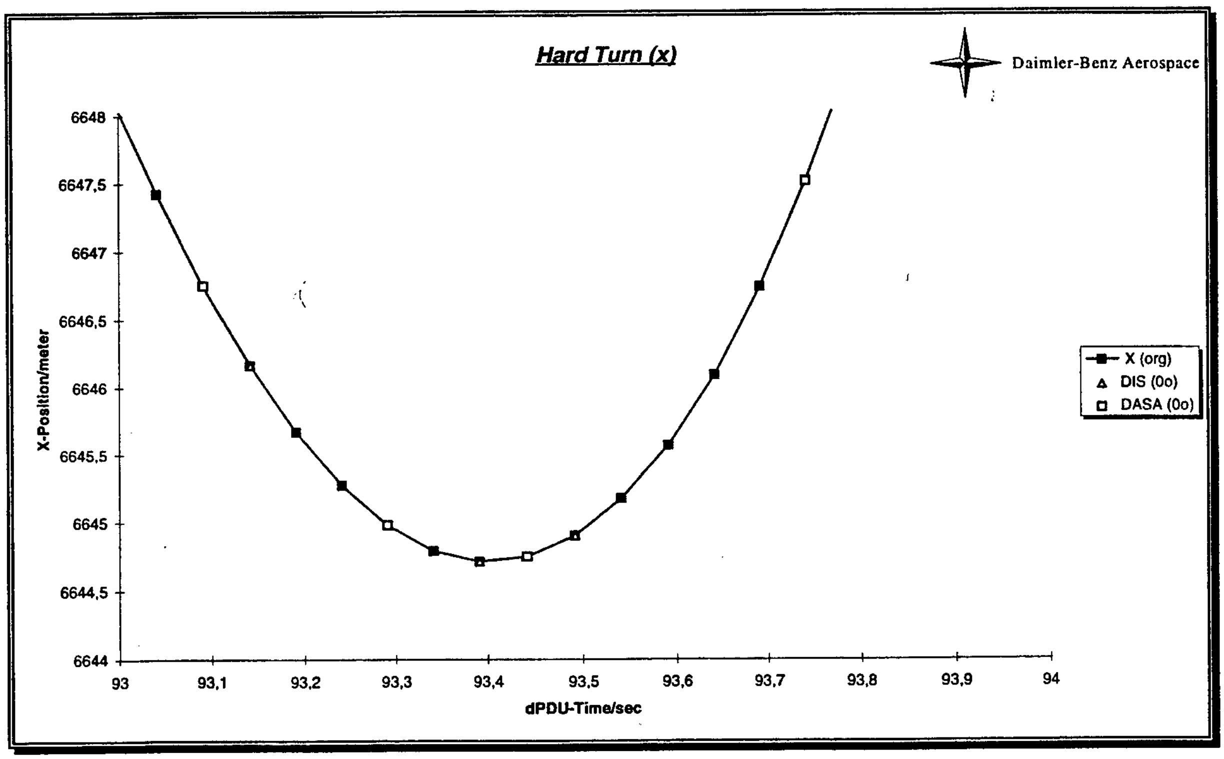


Fig. 6-24 Reference Flight path and Transmitted Values

Fig. 6-24 shows the X-value of the reference flight path. For comparison, the different protocols' transmitted data are printed using different colors and shapes. The measurements show that the transmitting algorithms accuracy parameters for both protocols were chosen correctly, thus the transferred data rate when compared to the originally produced data from the data recorder (simulating the simulator) was reduced by 70% on both protocols.

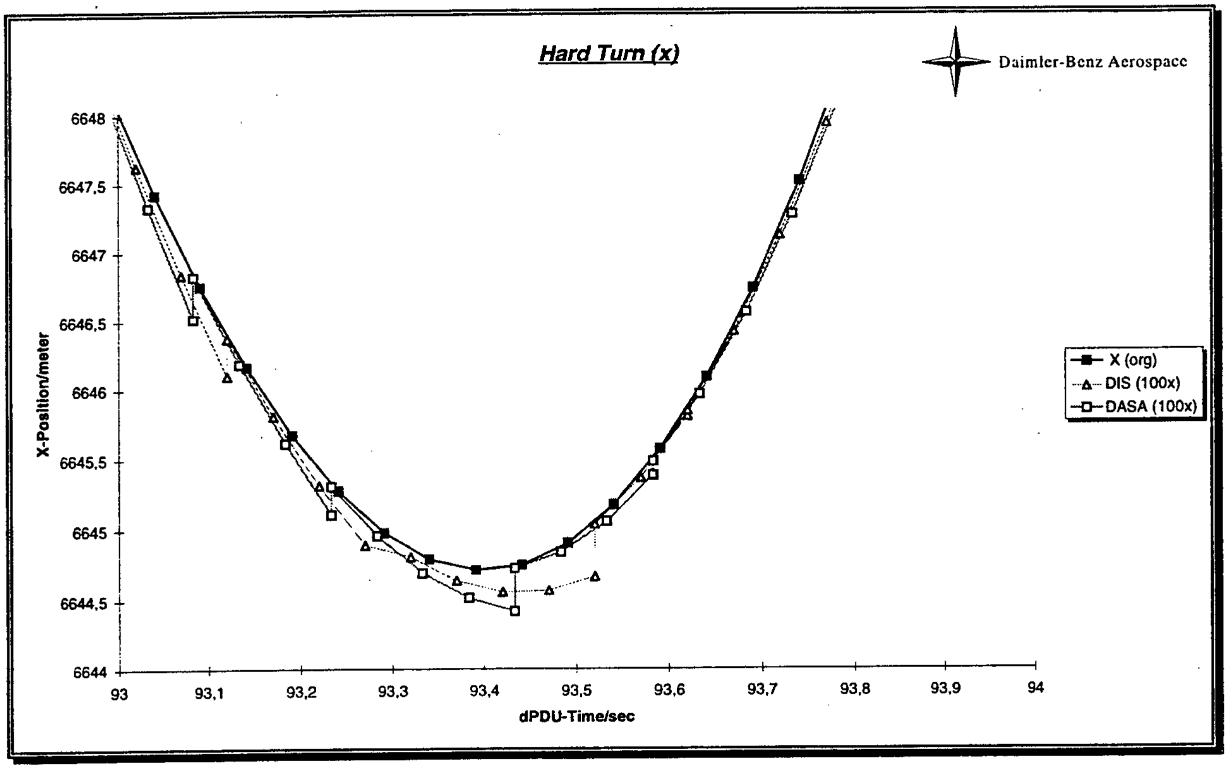


Fig. 6-25 Regenerated Flightpath in Comparison to the Referenced Flightpath

Fig. 6-25 shows the regenerated flight paths for both protocols at the receiving site with a delay of 100msec as compared to the referenced flight path. The diagram clearly shows the deviation of the extrapolated from the referenced flight path. As soon as a new data set is received the regenerated curves gets corrected to the actual value.

6.4.4.3 Evaluation of the Absolute Positioning Error

To compute the transmitting procedure's absolute error, the regenerated and the referenced values are subtracted from each other. The absolute values of the result can be graphically shown.

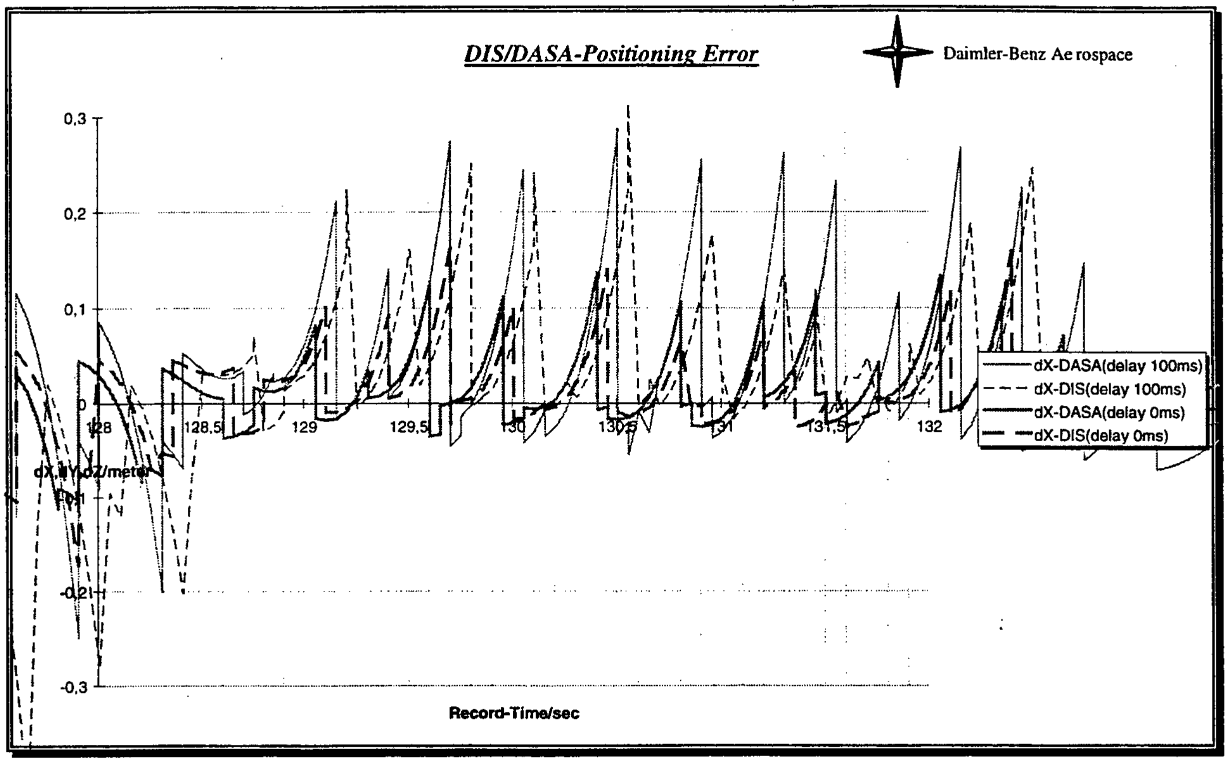


Fig. 6-26 Absolute Positioning Error

The positioning error caused by the reduced data transfer differs just trivially between the protocols. A closer look shows the error of the regenerated Dasa-Protocol values to be a bit better. The influence of the 100msec delay time is obvious and is characteristic of the transatlantic distance.

The computed absolute positioning error stays within the preset values as long as there is no added delay time. By adding the transatlantic delay, the error is multiplied by factor of 3. The highest absolute error value never exceeds 0.5 meter (in comparison: the aircraft moves about 33 meters when traveling at Mach 1 as it did in these tests).

6.4.4.4 Evaluation of the Absolute Flight angle Error

To compute each transfer procedure's absolute anglular error, the regenerated angles are subtracted from the referenced angles and the resulting absolute values can be plotted.

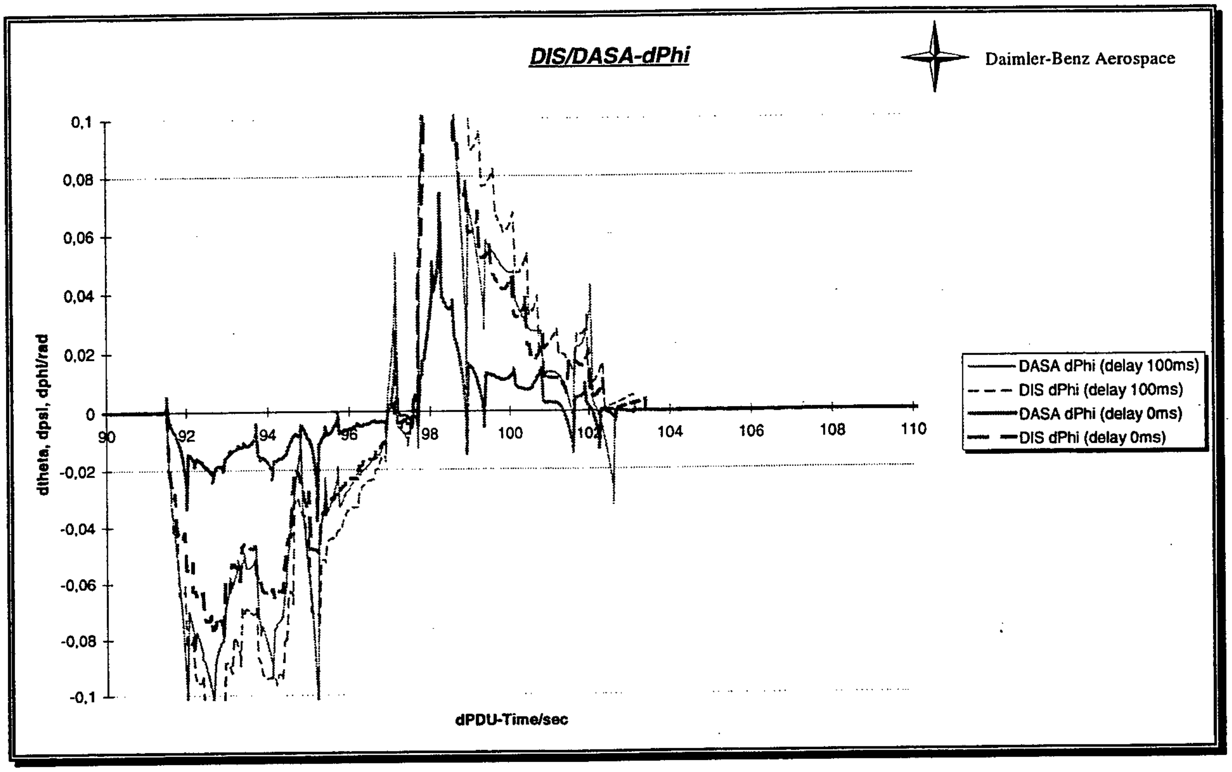


Fig. 6-27 Absolute Angle Error

The regenerated DIS-data errors differs from the reference angle values more than the regenerated Dasa-data. Again, the additional 100msec delay caused higher error values and again by a factor of 3.

6.4.4.5 Required Bandwidth

The required bandwidth for networked flight simulations is another interesting point to consider, since hardware must be bought or leased that can support these requirements. The following measurements of bandwidth requirements for the DIS- and Dasa- protocol depicts the requirements for one networked entity (aircraft) with its position and angle data. The influences of additional weapon systems, such as missiles and EW, are not taken into account in this analysis.

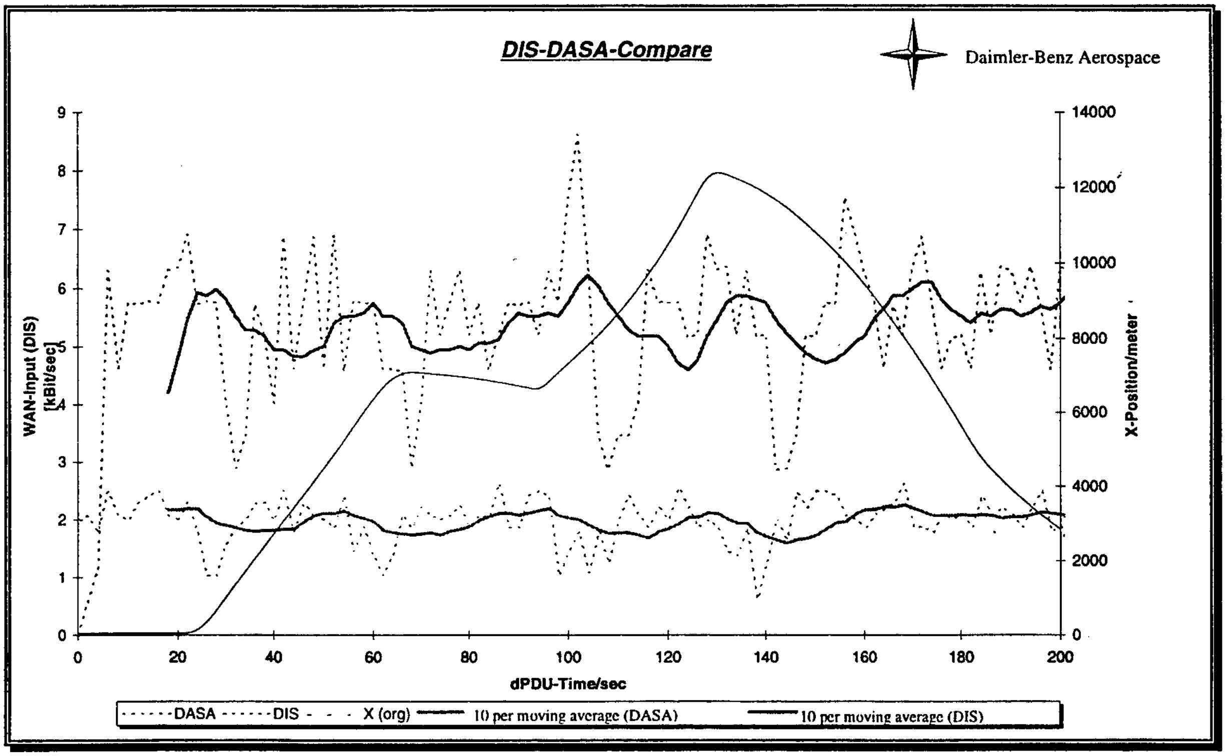


Fig. 6-28 Comparison of the Bandwidth Need

The diagram clearly shows a 50% reduction in the required bandwidth using the Dasa-Protocol as compared to the DIS-Protocol when using the same scenario with identical flight paths. The averaged lines in the diagram illustrate this more clearly. Also, the peak data rate values of DIS are quite high, making it difficult to extrapolate the bandwidth needs for increasing numbers of aircraft. Additionally, this may cause short period bandwidth limitations, even if the requirements were properly estimated. Furthermore, the use of weapon systems and models, i.e. high frequency missile models, will cause an increase in the bandwidth needed for both protocols. Because these results are based on a very simple scenario, the rehearsal oriented bandwidth need must be evaluated under more complex scenarios even if they are not directly comparable.

6.4.5 Production Run Bandwidth [Dasa]

6.4.5.1 Dasa PDU-Statistics

During the Production Runs, the following data were recorded for analyzing bandwidth usage and protocol features and quality:

- the number of PDU-packages used, for all three protocol types
- the number of active aircraft
- the number of active missiles
- the bandwidth used

Both input and output data were recorded. The output data represents the value sent to ensure adequate results at the receiving site. The input data represents the value the Dasa simulation actually received from the AFRL simulation. Due to the ISDN bandwidth limitations of 120 kbit/sec, the measured datarate on the input line cannot exceed 120 kbit/sec which may restrict the explicit number of received PDU's. Therefore, the analysis performed on the measurements is based on the output data.

In this chapter the Dasa-measurements during the Production Runs will be discussed in detail.
Mainly, the following four points of interest were analyzed:

- the used datarate
  Complex scenario data connections bandwidth requirements are very important since they tend to drive cost. There are always the input and output values to look at because of differences in the implementation of the Dasa NIC and implementation of the DIS/DIS-Lite-NIC at Air Force Research Laboratory and Daimler-Benz Aerospace AG.
- the required bandwidth as a function of the number of active entities
  The influence the number of entities has on bandwidth requirements indicates how to extrapolate bandwidth requirements for more complex scenarios from simple ones.
- the provided PDU-types usage
  Another important point is to determine which type of PDU is used most often or needed to fulfill the needs of a successful wide area networked simulation.
- the information dispersion of the PDU-types
  A percentage diagram of the quantity of each PDU-type as a function of the number of PDU's sent is needed.

Different types of PDU's are used to fulfill the requirements of the TRACE-scenarios.
The Dasa-PDU's are:

- CMD - contains command and control data
- EAP - contains the appearance and other low update rate data for an entity
- SDR - contains the dead reckoning data for a simple entity (e.g. missiles)
- CDR - contains the dead reckoning data for a complex entity
- RAD - contains the information for a radar warning receiver
- DEX - contains general information from entity to another

The DIS-PDU's are

- ES - contains entity state information
- FIR - contains information about a launched missile
- DET - contains information about a missile removal (hit or miss)
- EMI - contains emission data for warning receiver
- CMD - not used in DIS
- EAP - not used in DIS

The DIS-Lite-PDU's are:

- QR - contains the relatively static information about the entity state
- KINE - contains kinematics information about the entity state
- FIR - contains information about a launched missile
- DET - contains information about a missile removal (hit or miss)
- EMI - contains emission data for warning receiver
- CMD - not used in DIS-Lite

During the Production Runs, the pilots could not differentiate between the protocols as long as bandwidth limitations did not effect the quality of the simulation. If adequate quality could not be maintained using a particular protocol, it wouldn't be used in later runs.

6.4.5.1.1 Scenario 2: 1 v 1 Combat

In this scenario, two manned cockpits, equipped with complete weapon systems, are placed in opposition. These hostile entities perform combat with the objective to kill the opponent.

6.4.5.1.1.1 DIS-Protocol

6.4.5.1.1.1.1 Bandwidth

6.4.5.1.1.1.1.1 Bandwidth Usage

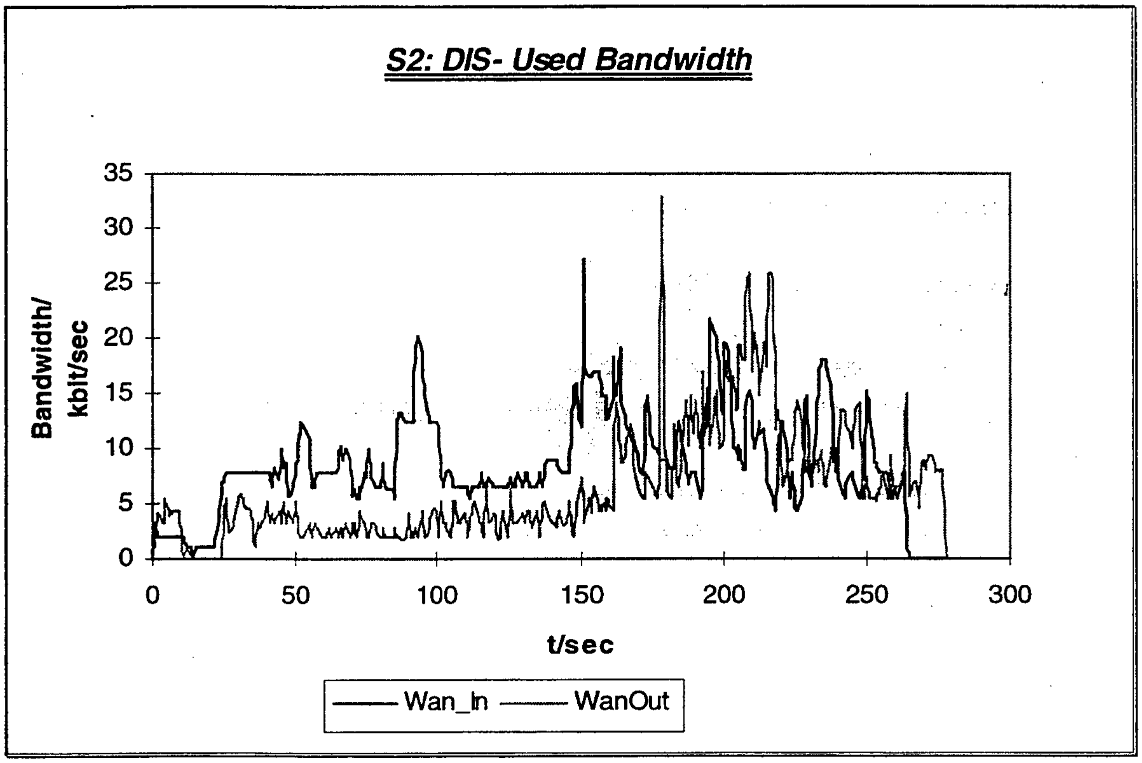


Fig. 6-29 S2- DIS- Used Bandwidth

The diagram shows that a bandwidth of approximately 5 to 25 kbit/sec is needed for scenario S2. The difference between the input and output values comes from the different behavior of the pilots (the AFRL-pilot is more maneuverable in this phase).

The diagram shows about 150 seconds of approach before the combat phase begins.

6.4.5.1.1.1.1.2 Bandwidth as a function of the number of entities

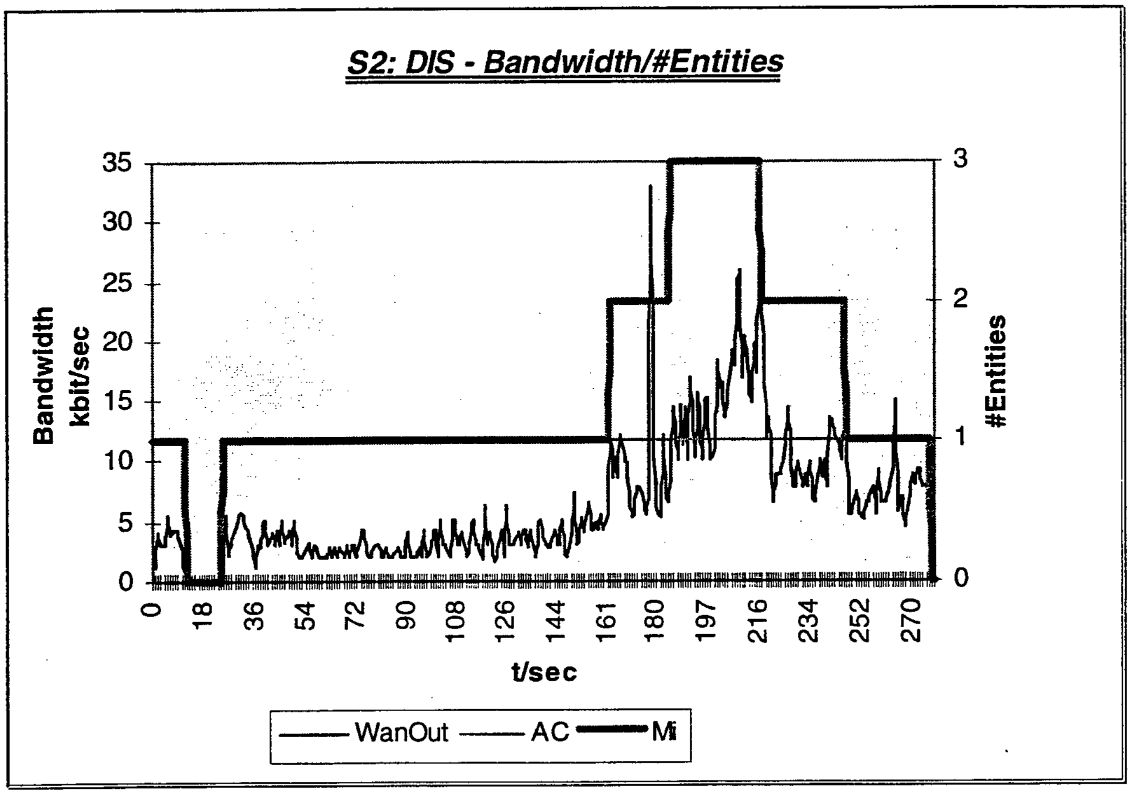


Fig. 6-30 S2- DIS- Used Bandwidth/#Entities

The diagram above shows the required bandwidth for the output of the Dasa simulator as a function of the number of active entities. The small AC line represents the number of aircraft (in this scenario there is 1 aircraft on both AFRL and Dasa sides). In scenario S2, Dasa is responsible for 1 aircraft and its missiles. The line for the number of active missiles is added to the line for the number of aircraft. Therefore, the wide line represents missiles + aircraft = overall number of represented entities

Between 10 and 20 seconds, the number of missiles and aircraft drops to zero due to Dasa resetting its simulation. As you can see, the bandwidth drops to zero.

At about time = 160 seconds, the combat phase begins. The number of missiles on the Dasa simulation increases from 0 to 1 and then to 2. As the first missile burned out, the number of missiles drops again to 1 before the second missile hits the AFRL target.

As the each missile is launched, the bandwidth increases to allow the data for the new high speed entity to be continuously transferred. With both missiles, the bandwidth requirement is up to 25 kbit/sec but drops as the missiles burn out and are removed.

When just one aircraft is active, there is a constant need for a bandwidth of approximately 5 kbit/sec.

6.4.5.1.1.1.2 PDU-Statistics

6.4.5.1.1.1.2.1 Number of PDU's as a Function of the Number of Entities

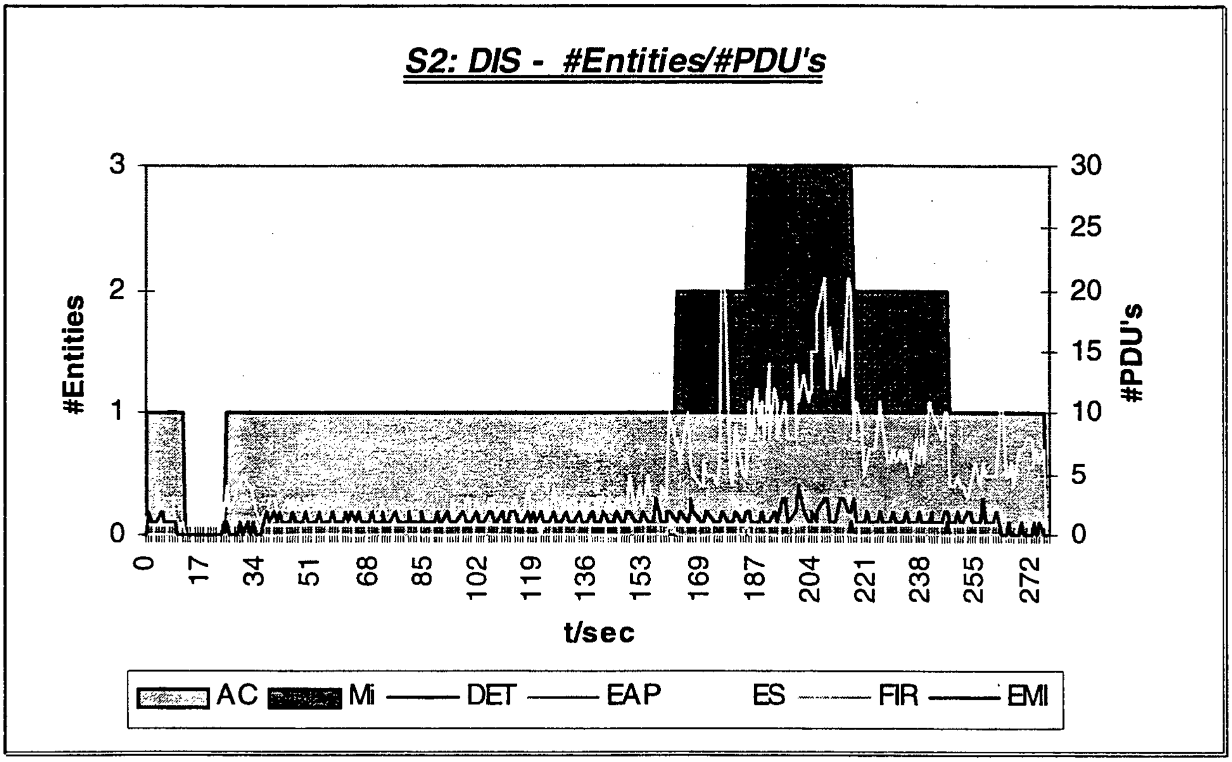


Fig. 6-31 S2- DIS- #Entities/#PDU's

This diagram above shows the PDU-types needed for correct data transfer and regeneration at the connected site as a function of number of active entities. Again, the number of active missiles and active aircraft are added. In this scenario, the Dasa simulator is responsible for only one aircraft.

As before, the reset of the Dasa simulator and the onset of the combat phase with the launching of missiles can clearly be seen.

While the aircraft approach one another, some ES-PDU's (Entity State) and some EMI-PDU's, representing the radar emission of the aircraft's radar model, are transmitted.
As the first missile is launched, one FIR-PDU's (Fire-PDU) is sent and the number of ES-PDU's increases due to the transmission of data for the new high speed entity.

The EMI-PDU's increase because of the emissions of the missile's seeker head.

As the missile is removed, the DET-PDU (Detonation-PDU) is sent to indicate the reason a it was removed.

6.4.5.1.1.1.2.2 Assignment of PDU-Types over one Complete Run

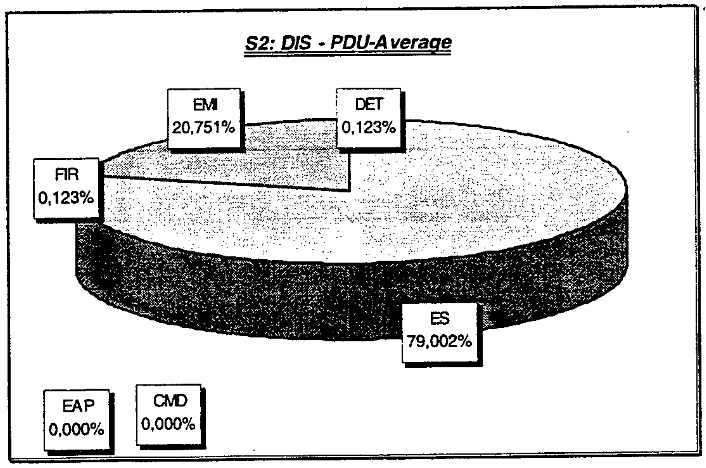


Fig. 6-32 S2- DIS PDU-Percentage

The diagram shows that the ES-PDU (Entity-State) and the EMI-PDU (Emission-PDU), which holds the scenario's radar information, use the majority of the bandwidth with the ES-PDU having the largest demand on bandwidth. Also, for each missile launched, firing information (FIR-PDU) and detonation information DET-PDU (Detonation-PDU indicates the reason missile was removed) is sent.

6.4.5.1.1.2 DIS-Lite-Protocol

6.4.5.1.1.2.1 Bandwidth

6.4.5.1.1.2.1.1 Bandwidth Usage

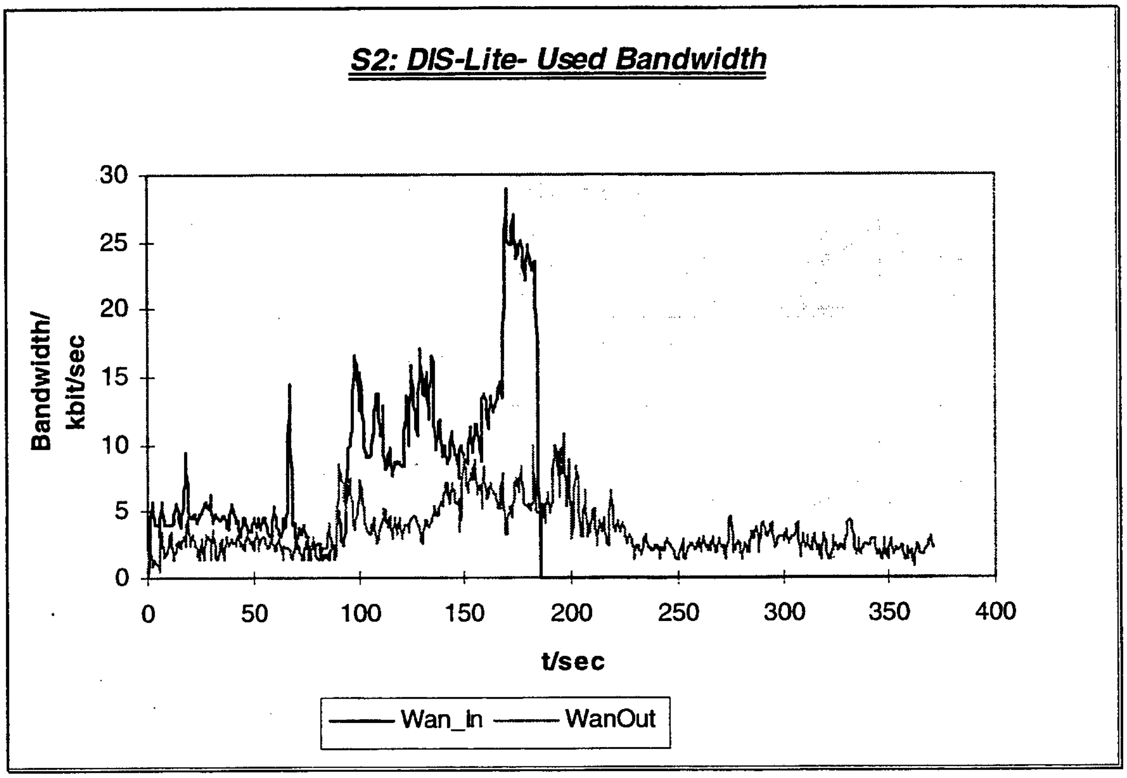


Fig. 6-33 S2- DIS-Lite- Used Bandwidth

The diagram above shows the bandwidth usage for scenario S2 using the DIS-Lite-protocol. The value of the input is again higher in comparison to the output because of time synchronization as discussed above.
During the approach phase, a bandwidth of 3 to 5 kbit/sec is needed to transmit the required data from each simulation. In the combat phase, which starts about time = 90 seconds, the bandwidth need increases by 10 kbit/sec to 15 kbit/sec for the incoming line because of launched missiles and more agile aircraft.
The high peak in bandwidth on the "Wan-In"-line is a result of the tailspin after a missile hit on the AFRL-target which causes the dead reckoning algorithm to transfer very high frequency entity state information. The movement of a dead entity can cause problems if the bandwidth limits of the transfer media is reached.

6.4.5.1.1.2.1.2 Bandwidth as a function of the number of entities

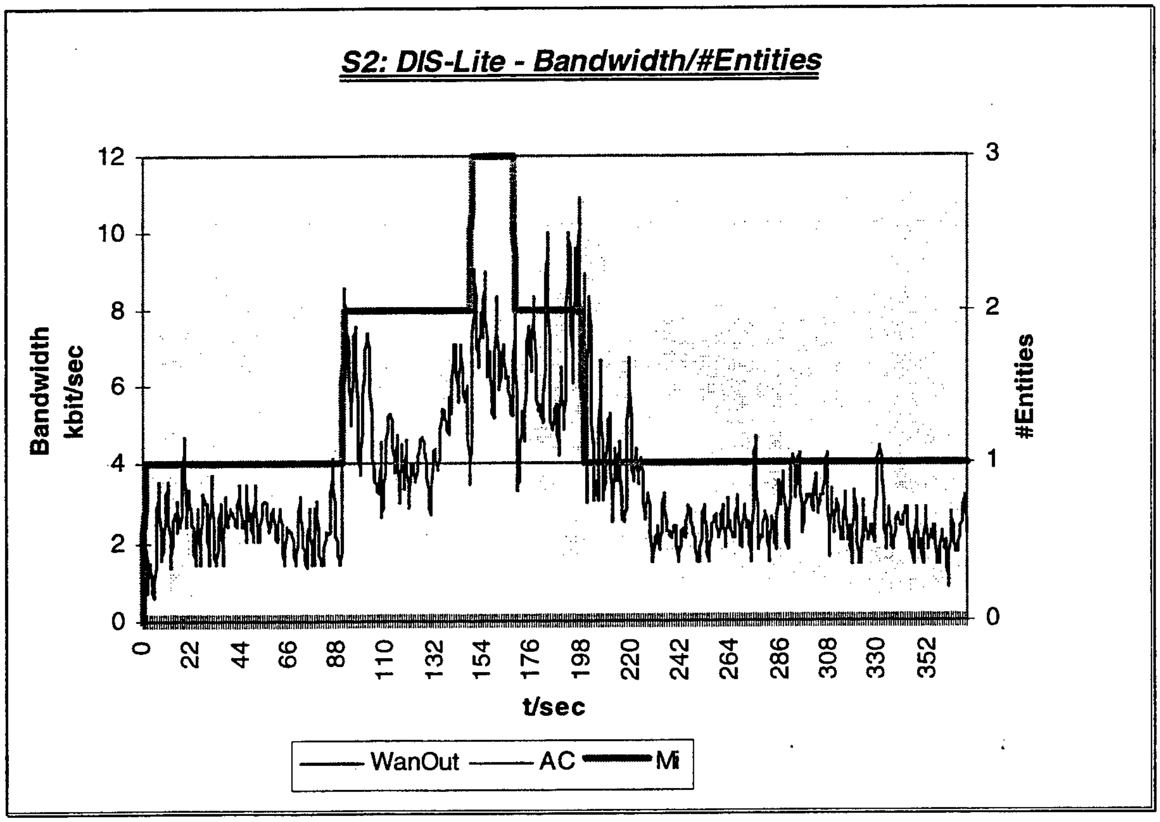


Fig. 6-34 S2- DIS-Lite- Used Bandwidth/#Entities

For a closer look at how bandwidth depends on the number of active entities, the diagram shows the amount of outgoing information drawn with respect to the additive number of entities.

During the approach phase, the Dasa simulation aircraft needs a relatively constant 3 kbit/sec bandwidth. As a missile is launched, the bandwidth need increases to fulfill the required information exchange for the newly created high speed target. Once the missile flies the precalculated flight path, the bandwidth required drops again from 8 kbit/sec to 4 kbit/sec. As the next missile is launched by the Dasa-simulator, there is again a bandwidth increase to 8 kbit/sec but this time it does not decrease after the first missile is removed. The reason for the bandwidth not decreasing is the hit on the target. After all missiles are removed the returns to the normal level (approach phase level).

6.4.5.1.1.2.2 PDU-Statistics

6.4.5.1.1.2.2.1 Number of PDU's as a Function of the Number of Entities

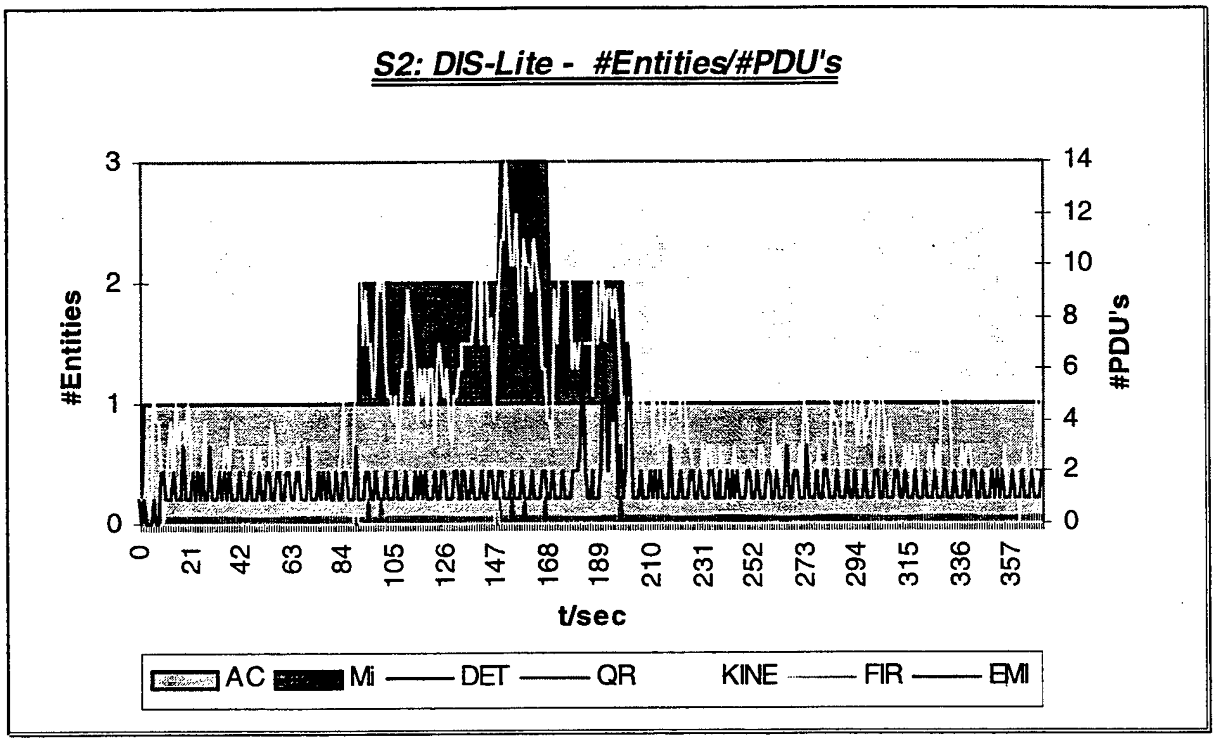


Fig. 6-35 S2- DIS-Lite- #Entities/#PDU's

The approaching entity's state is transferred by a small number of EMI-PDU's, containing the emission data, and a few KINE-PDU's containing the dynamic information about the entity state. The radar was not active at the very beginning and was switched on after a few seconds. As a missile is launched, a FIR-PDU is sent indicating the launch, some QR-PDU's are sent containing the relatively static entity state information and KINE-PDU's are sent for high dynamic data exchange. Because missiles are high speed entities, information is transferred at a high rate.

The high rate of KINE-PDU's, after time = 170 seconds, are the result of a missile avoidance maneuver by the Dasa-aircraft and is the reason for the increase of EMI-PDU's, which transfers the IR information in the DIS and DIS-Lite- protocols. Agile maneuvers with use of afterburners cause the need for IR- information exchange.
For some unknown reason, the implementation of the DIS-Lite protocol was sending EMI-PDUS to entities that had already been removed from the scenario, which doesn't occur when using the other protocol.

6.4.5.1.1.2.2.2 Assignment of PDU-Types over one Complete Run

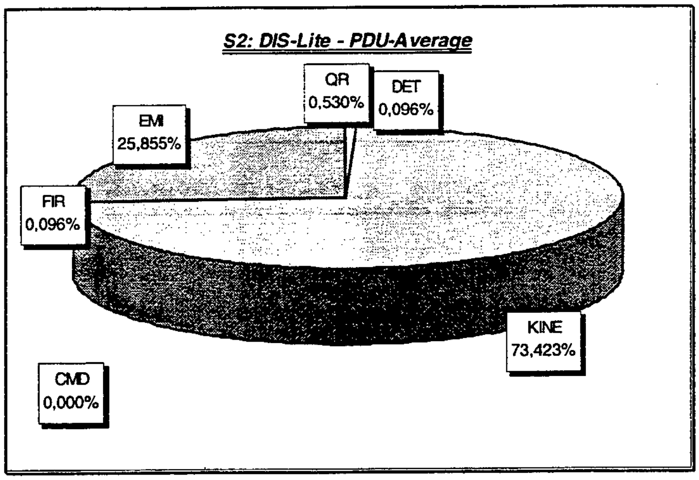


Fig. 6-36S2- DIS-Lite PDU-Percentage

Quantitatively, the KINE-PDU's transfer most of the data exchanged and are supported by a small number of QR-PDU's, which contain the rest of the entity state information.

The emission information is the second largest user of bandwidth, accounting for a quarter of the transferred data packages.

For each missile launched, FIR- and DET-PDU's were sent to inform the partner about the new or removed target.

6.4.5.1.1.3 Dasa-Protocol

6.4.5.1.1.3.1 Bandwidth

6.4.5.1.1.3.1.1 Bandwidth Usage

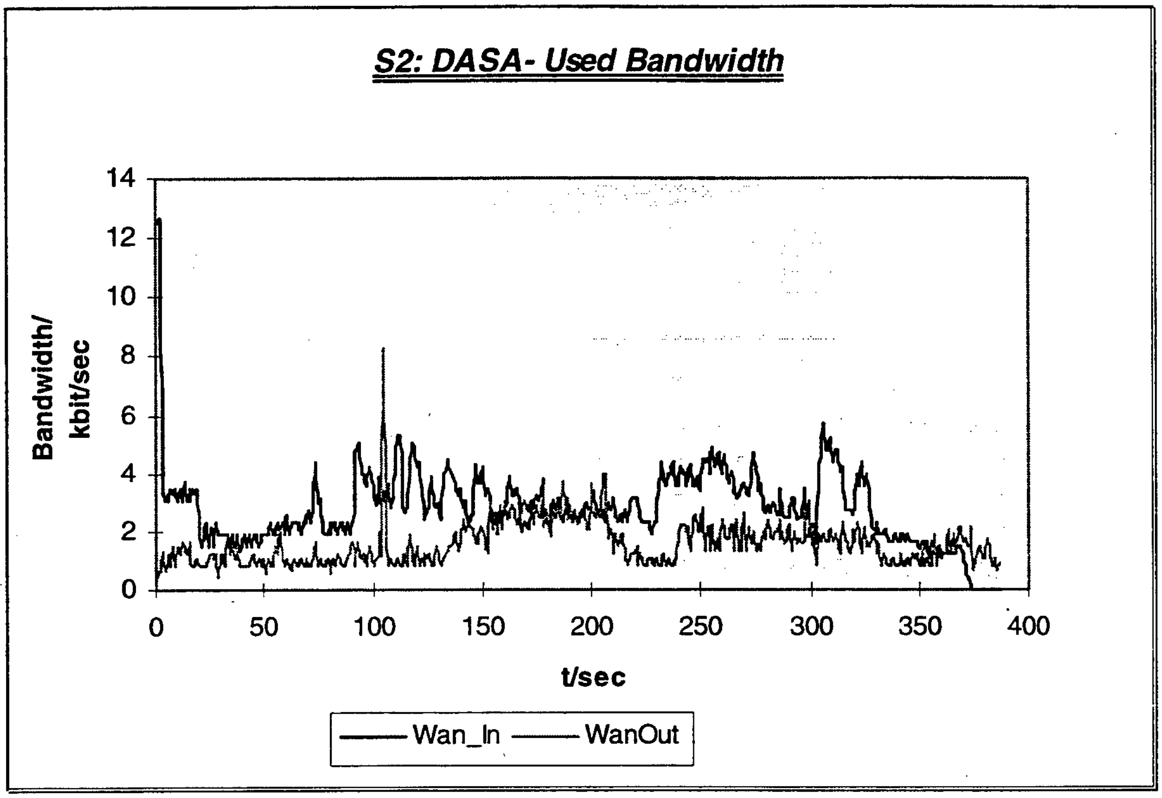


Fig. 6-37 S2- Dasa- Used Bandwidth

As previously discussed, the value of the incoming data is higher than that of the outgoing as a result of better time synchronization at the Dasa site.

During the approach phase, one entity on each site needs about 2 kbit/sec of bandwidth (4 kbit for the input data). There is a slight increase in the bandwidth needed (to about 3 kbit/sec) as the combat phase begins at t = 120 seconds.

There is no explanation for the peak at t = 100 seconds.

At t = 300 seconds, the effect of a tailspin from the AFRL side can again be seen. This tailspin causes a high rate of data to be exchanged because of its incalculable movements. In effect, it doubles the bandwidth required for that period of time and can cause problems if the bandwidth limitations are exceeded.

6.4.5.1.1.3.1.2 Bandwidth as a function of the number of entities

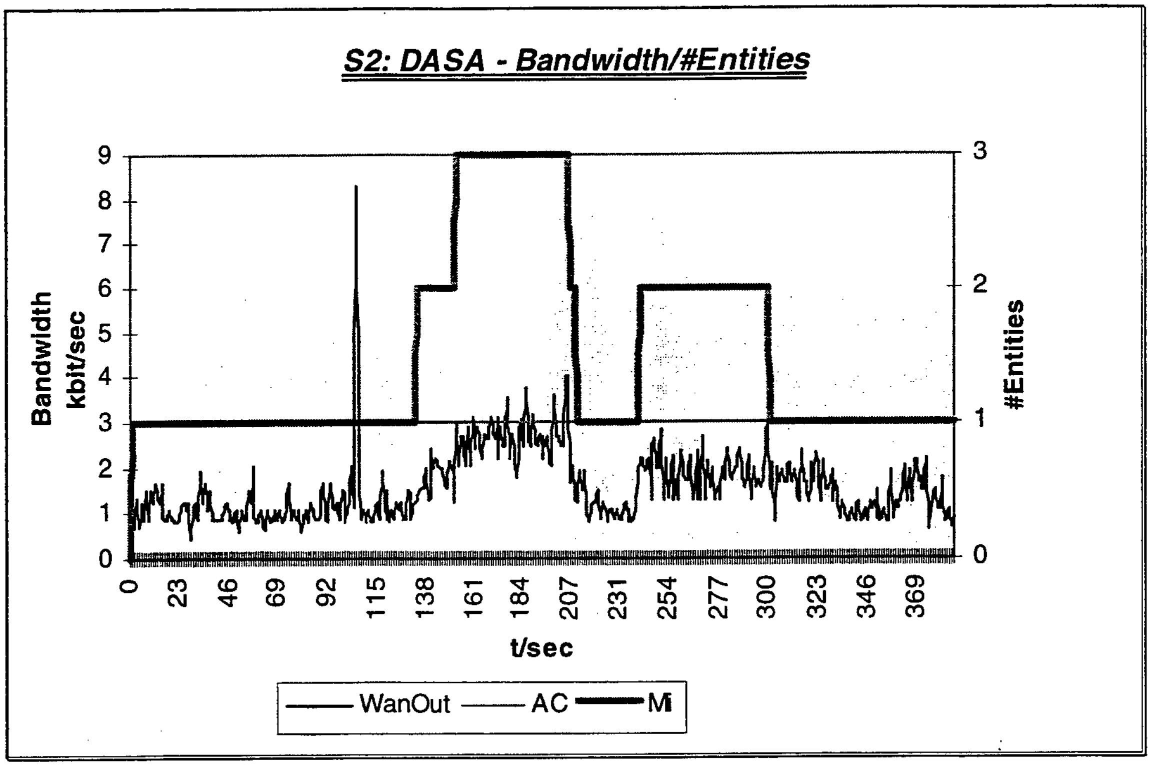


Fig. 6-38 S2- Dasa- Used Bandwidth/#Entities

During the single entity's approach phase, a bandwidth of 1 to 2 kbit/sec is needed. As the combat phase begins and two missiles are launched, the required bandwidth increases to 3 kbit/sec. In the second launch period at t = 240 seconds, the single launched missile is covered by a datarate of 2 kbit/sec.

Even this diagram gives no explanation for the peak in bandwidth usage at t = 100 seconds. There is no change in the number of entities which could cause this effect.

6.4.5.1.1.3.2 PDU-Statistics

6.4.5.1.1.3.2.1 Number of PDU's as a Function of the Number of Entities

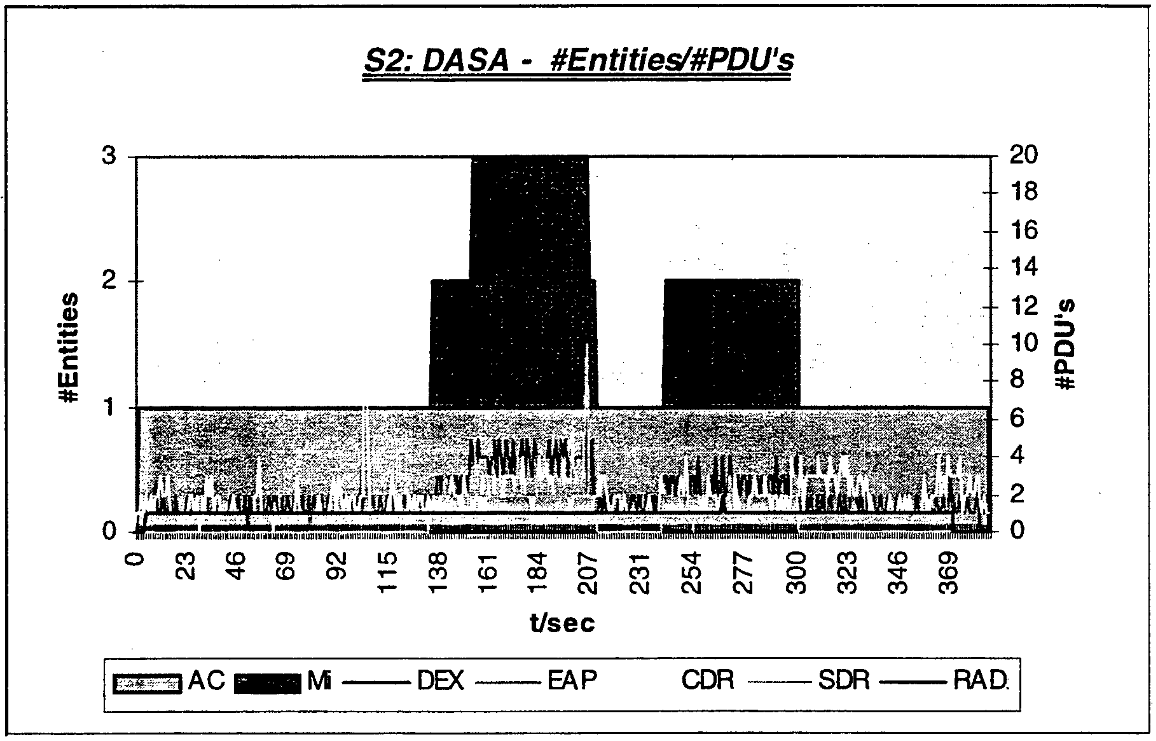


Fig. 6-39 S2- Dasa- #Entities/#PDU's

During the approach, the single aircraft requires only a few EAP-PDU's (Entity Appearance) and a few CDR-PDU's (Complex Dead Reckoning) to describe its state.
To handle the radar systems emission information, a constant amount RAD-PDU's (Radar-PDU) is exchanged.

At the moment the first missile is launched, the number of EAP-PDU's increases and a few SDR-PDU's (Simple Dead Reckoning), containing the missile kinematics data, are sent to the other simulator.

Immediately after the second missile is launched the aircraft performed a evasive maneuver causing the number of CDR-PDU's to increase. These PDU's describe the aircraft's kinematics.
Notice that as the missiles disappear, the number of all PDU-types decrease.

The second missile launch period confirms the results as well.

This diagram shows that the spike in the bandwidth observed in the previous diagrams is caused by a high number of CDR-PDU's. Since these PDU's describe the state of the aircraft, the resultant spike may be the result of high dynamic movements of the aircraft such as sudden rolls and/or dives.

6.4.5.1.1.3.2.2 Assignment of PDU-Types over one Complete Run

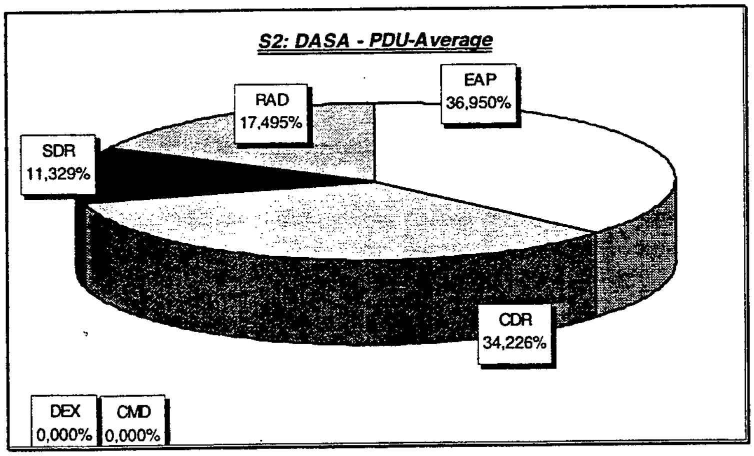


Fig. 6-40 S2- Dasa PDU-Percentage

Notice, in the diagram, that the quantity of EAP- and CDR-PDU's sent are nearly equal. Additionally, some SDR-PDU's, transferring missile relevant information, are sent as a result of firing missiles.

The RAD-PDU's, which contain radar warning receiver data, complete the diagram.

6.4.5.1.1.4 Protocol Comparison

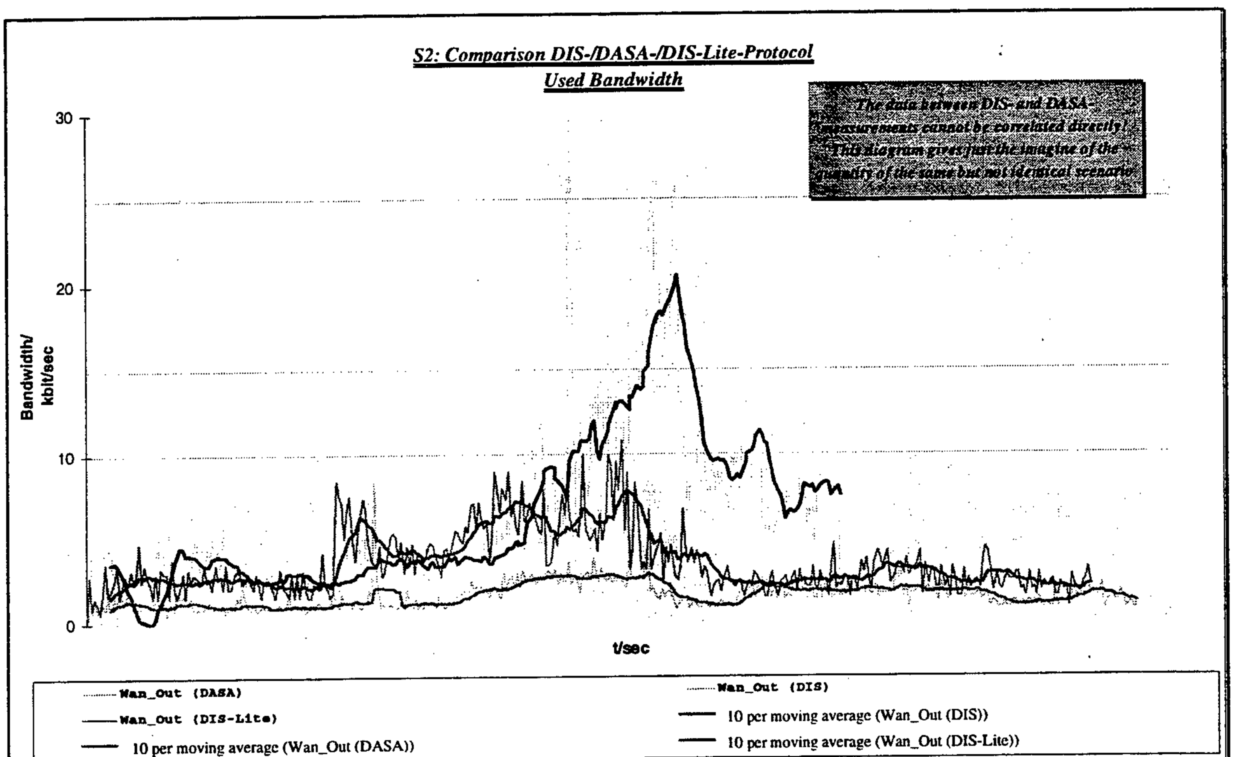


Fig. 6-41 S2 Protocol Comparison

The diagram above compares the bandwidth used by each protocol during scenario S2. The graphs are not directly comparable since the pilots learned from each run and changed their tactics for the next run. However, the plots do give a relative idea of how the average bandwidths required by each protocol would compare. For

the analysis, runs with similar complexity were chosen, especially where the number of entities were concerned. The runs were not identical but the scenario and its complexity were the same.

To get a better idea of the values, a moving average with a period of 10 was calculated for each recorded line.

Notice that the DIS-Protocol is erratic and has the highest bandwidth requirements, with maximum averaged rates of up to 20 kbit/sec and a measured peak bandwidth requirements out to 30 kbit/sec.

Notice also, that the DIS-Lite-protocol is also very erratic but that its bandwidth requirements are approximately one third that of the DIS-Protocol.

The Dasa-Protocol shows a smoother behavior (less variation between peaks and valleys) and a lower bandwidth requirement. The averaged line shows the required bandwidth for the Dasa-Protocol to be one third that of the DIS-Lite-protocol's and one ninth that of the DIS-protocol's.

All measurements depict a low datarate during the approach phases and a steady increase in required bandwidth when missiles are added to the scenario during combat phase.

Protocol	***average bandwidth need***	***peak bandwidth need***
DIS	<20 kbit/sec	<30 kbit/sec
DIS-Lite	<7 kbit/sec	<10 kbit/sec
Dasa	<3kbit/sec	<3kbit/sec

6.4.5.1.2 Scenario 3: 2 v 2 Combat

In this scenario, two hostile forces each consisting of two manned cockpits equipped with full weapons systems were generated. The objective was to destroy the hostile force using MRMs and/or SRMs.

6.4.5.1.2.1 DIS-Protocol

6.4.5.1.2.1.1 Bandwidth

6.4.5.1.2.1.1.1 Bandwidth Usage

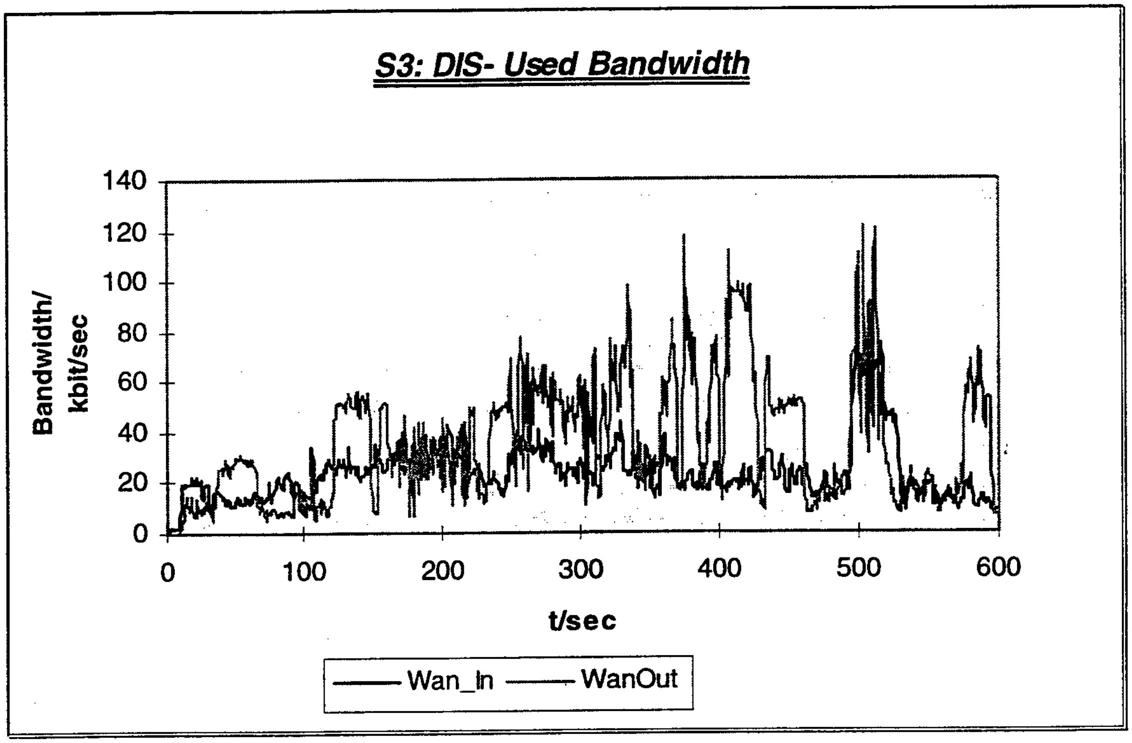


Fig. 6-42 S3- DIS- Used Bandwidth

The diagram shows that a bandwidth of approximately 20 to 120 kbit/sec is needed for scenario S3. The differences between the input and output values come from the difference in pilot behavior and use of weapons (this time, the Dasa-pilots were more maneuverable and launched more missiles in a short period of time); therefore, input and output values are not directly comparable.

Since more aircraft are involved in this scenario, the approach phase is not as evident as in scenario S2.

The high bandwidth requirement shown on the input line (Wan_In), at about t = 500 seconds, was caused by the behavior of a destroyed AFRL-aircraft.

6.4.5.1.2.1.1.2 Bandwidth as a function of the number of entities

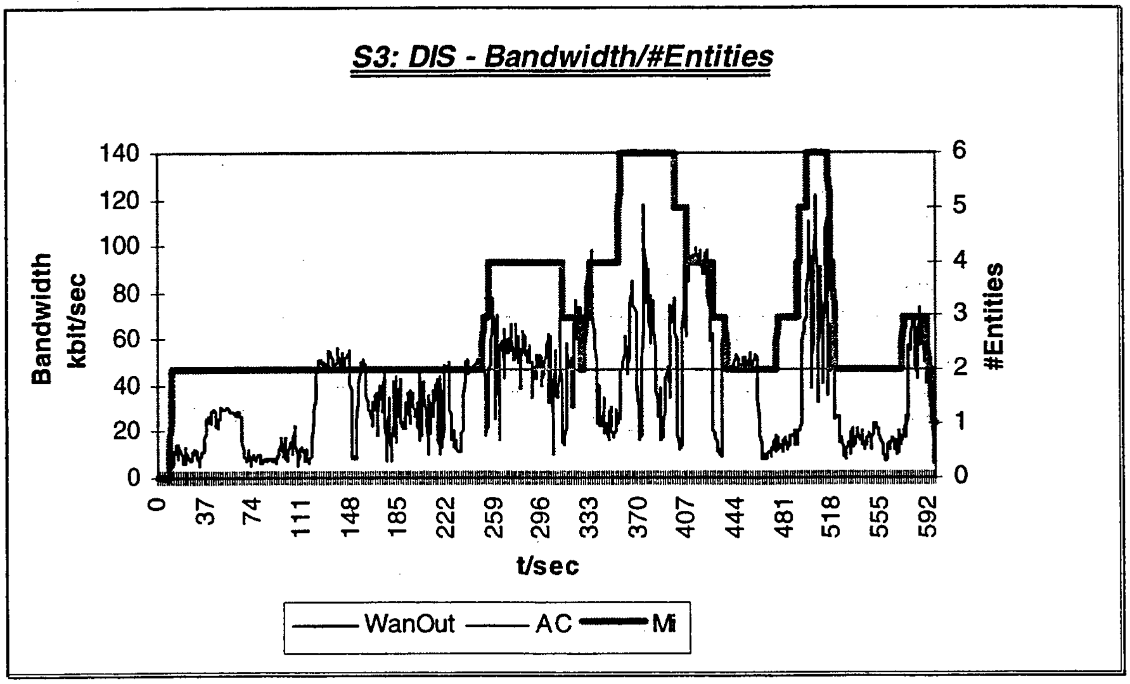


Fig. 6-43 S3- DIS- Used Bandwidth/#Entities

The diagram shows the required bandwidth for the Dasa simulator's output as a function of the number of active entities. The narrow line represents the number of aircraft (in this scenario there are two aircraft each at both AFRL and Dasa). In scenario 3, Dasa controls two aircraft and their missiles. The number of active missiles is added to the number of aircraft yielding the wide line which represents

missiles + aircraft = overall number of represented entities.

At about t = 250 seconds, the first two missiles were launched, causing a higher average required bandwidth of about 50 kbit/sec. This requirement remained while the missiles were active. Before the missiles were fired, before t = 250 seconds, the two maneuverable aircraft required a bandwidth of between 20 and 40 kBit/sec. During the next two launch periods, where a total of 4 missiles were launched, the instantaneous bandwidth requirements were inconsistent with variations between 20 to 120 kBit/sec. It appears that all the missiles were fired at the same aircraft and were removed with the AFRL-entity. The bandwidth needed for the remaining two aircraft returned to the value it was at during the approach phase.

At the end, one additional missile was launched before one of the Dasa-entities and the last AFRL-entity were killed.

As long as the two active aircraft are agile, they need a datarate of up to 40 kBit/sec. If they are not maneuvering (flying straight), a bandwidth of about 10 kBit/sec is needed for complete coverage. Additionally, one missile can increase the required bandwidth to 60 kBit/sec. Peaks of up to 120kBit/sec can be seen when 4 missiles are active.

6.4.5.1.2.1.2 PDU-Statistics

6.4.5.1.2.1.2.1 Number of PDU's as a Function of the Number of Entities

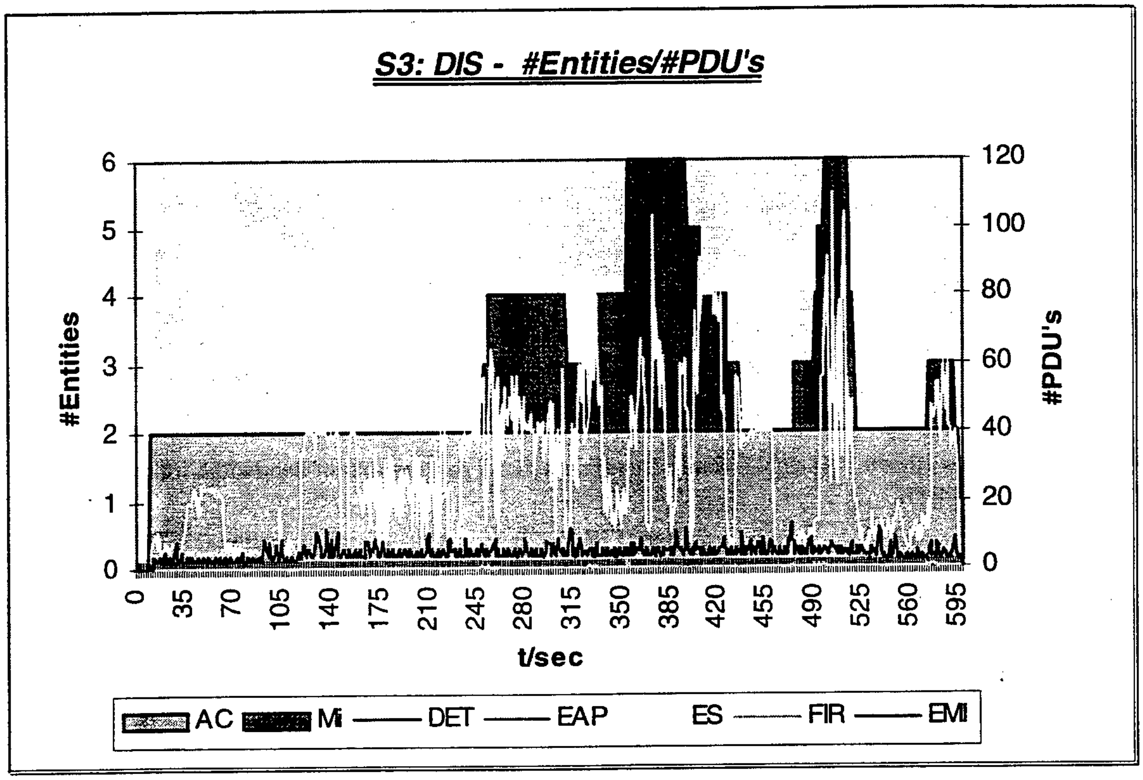


Fig. 6-44 S3- DIS- #Entities/#PDU's

This diagram shows the number of each type of PDU transmitted versus the number and type of active entity. It depicts the types of PDU's required to transmit data between the two simulators for successful regeneration at the opposite site. Again the number of active missiles is added to the number of active aircraft. In this scenario, Dasa controls two aircraft and their missiles.

The relatively small number of FIR-, DET- and EAP-PDU's are not as visible as they were in the simpler scenario S2 as a scaling result.

While the aircraft are approaching one another, there are some ES-PDU's (Entity State) and some EMI-PDU's (radar emissions and/or IR information).

The number of ES-PDU's increase as agile maneuvers are being performed in preparation for combat.

The first missile launch causes the number of ES-PDU's to increase because of the exchange of data for the new high speed entities.

The number of EMI-PDU's decreases in relative importance to the number of ES-PDU's transmitted, but is nevertheless higher than for the equivalent number of scenario S2.

6.4.5.1.2.1.2.2 Assignment of PDU-Types over one Complete Run

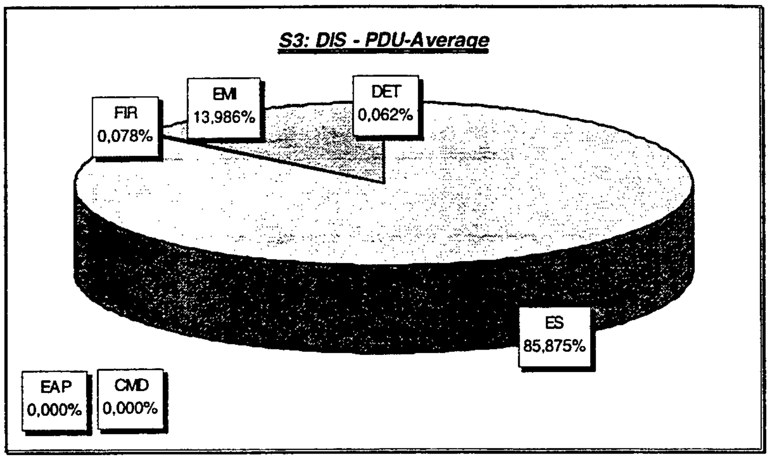


Fig. 6-45 S3- DIS PDU-Percentage

The diagram shows that the ES-PDU (Entity-State) uses the largest amount of bandwidth followed by the EMI-PDU (Emission-PDU).

For each missile launched, a firing information (FIR-PDU) and detonation information (DET-PDU) is sent.

6.4.5.1.2.2 DIS-Lite-Protocol

6.4.5.1.2.2.1 Bandwidth

6.4.5.1.2.2.1.1 Bandwidth Usage

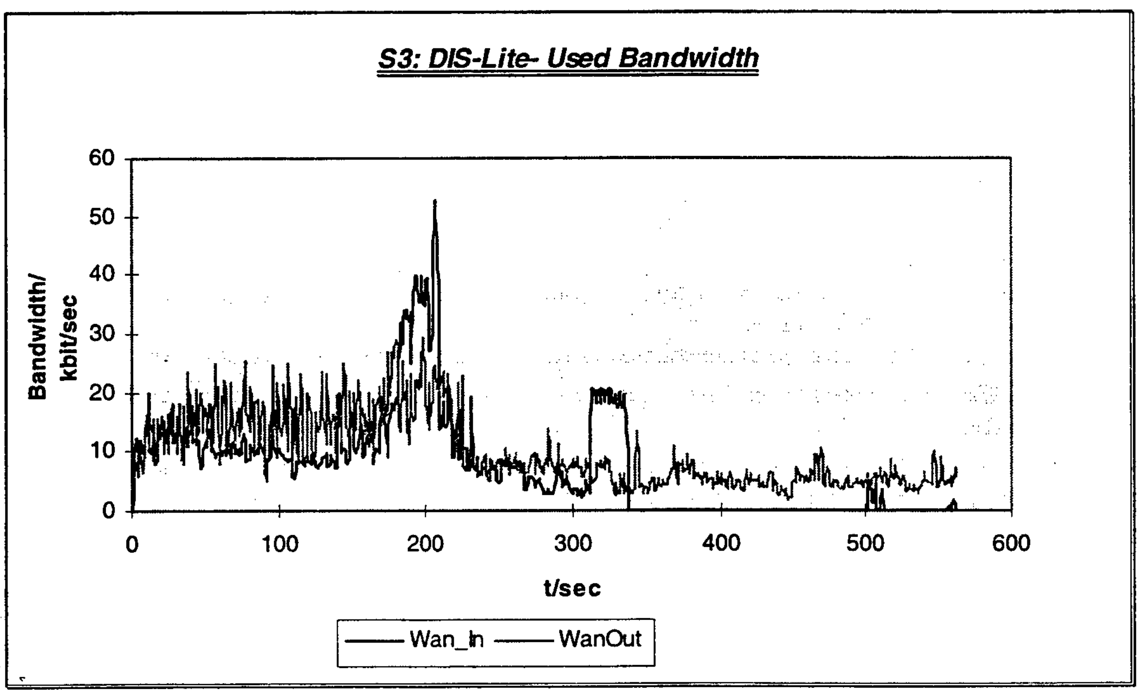


Fig. 6-46 S3- DIS-Lite- Used Bandwidth

The high peak in bandwidth on the "Wan-In"-line at t = 200 and 310 seconds is a result of the dead reckoning algorithm transferring a large amount of entity state data in response to a tailspin from a destroyed AFRL-target.

6.4.5.1.2.2.1.2 Bandwidth as a function of the number of entities

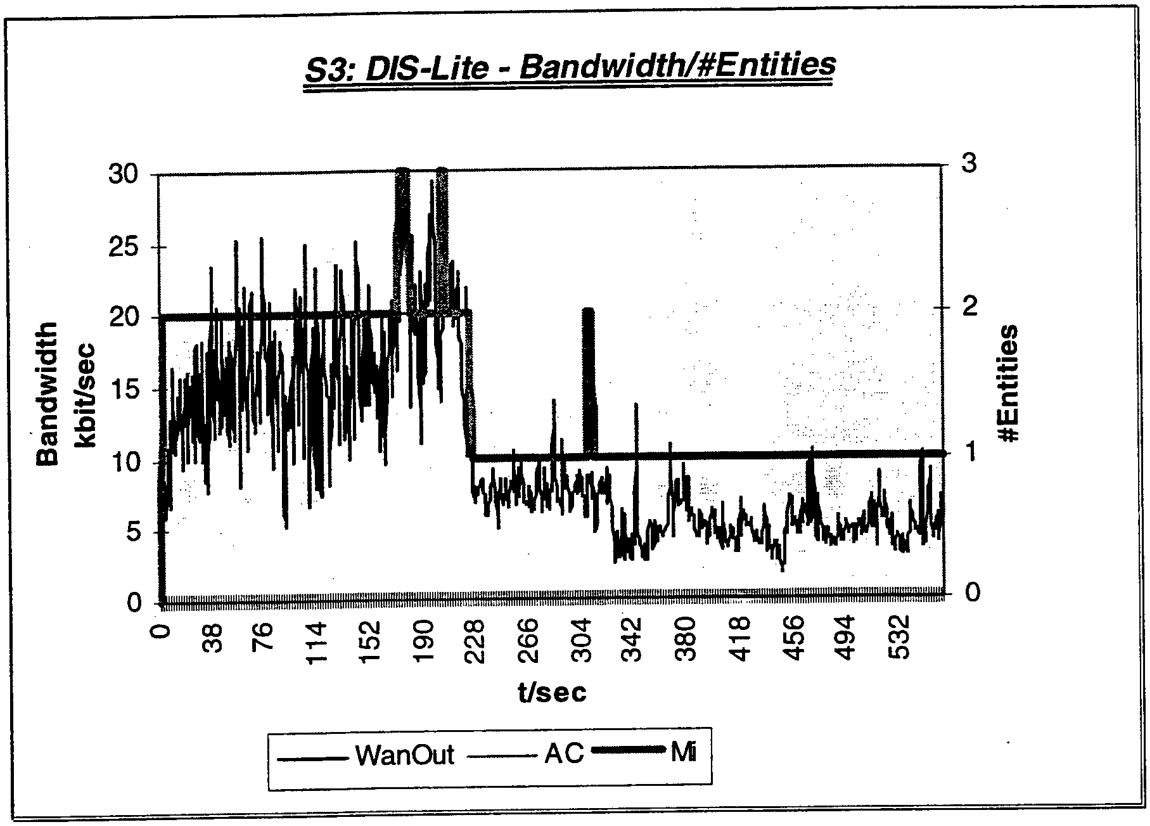


Fig. 6-47 S3- DIS-Lite- Used Bandwidth/#Entities

To determine how the bandwidth depends on entity count, the amount of outgoing information (required bandwidth) and active entity count are plotted versus time in the above diagram.

During the approach phase, the two Dasa-aircraft need a relatively noisy 10 to 20 kbit/sec bandwidth. At the moment a missile is launched, the transfer of information for the new high speed entity increases the required bandwidth only slightly but also results in peaks of up to 30 kbit/sec.

At the moment one of the two Dasa-aircraft is destroyed (t = 220 seconds), the datarate drops to 5 to 10 kbit/sec, which is still slightly higher (especially the peaks) than the datarate for one target in scenario S2. There are no obvious reasons for this difference.

6.4.5.1.2.2.2 PDU-Statistics

6.4.5.1.2.2.2.1 Number of PDU's as a Function of the Number of Entities

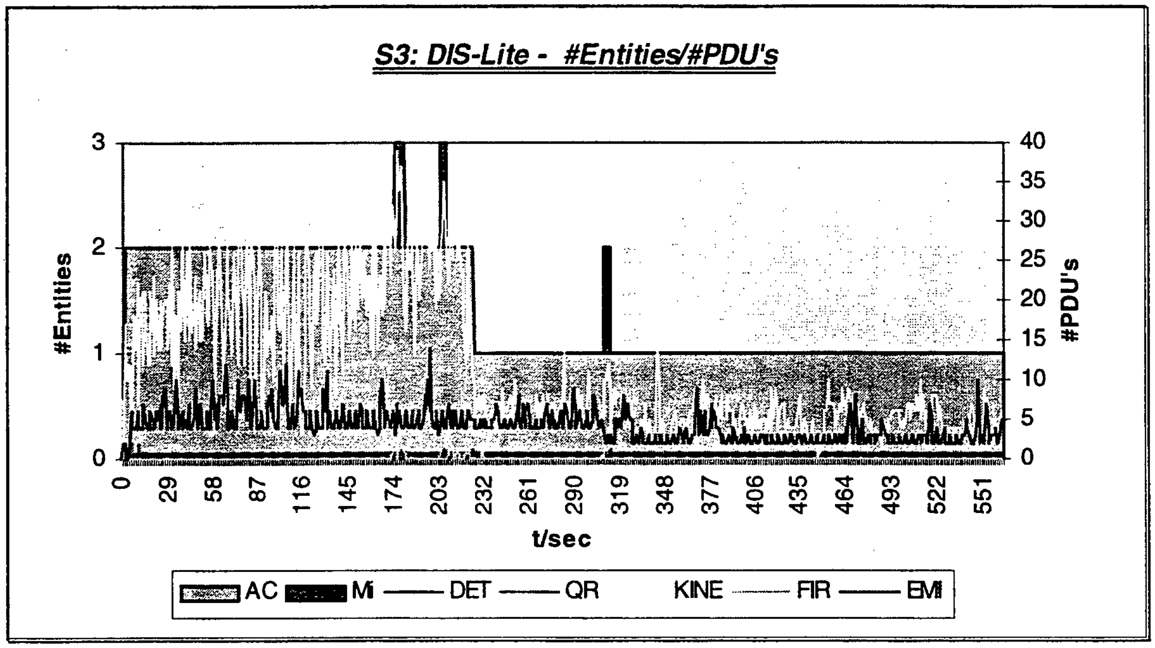


Fig. 6-48 S3- DIS-Lite- #Entities/#PDU's

A high number of KINE-PDU's (containing the high dynamic information about the entity state) and a small number of EMI-PDU's (containing the emission data) transfer the state of the approaching. Launching a missile results in a FIR-PDU, some QR-PDU's, and a large number of KINE-PDU's being sent. These PDU's indicate that a missile has been fired, relatively static information about the entity, and the dynamic information about the entity, respectively.

6.4.5.1.2.2.2.2 Assignment of PDU-Types over one Complete Run

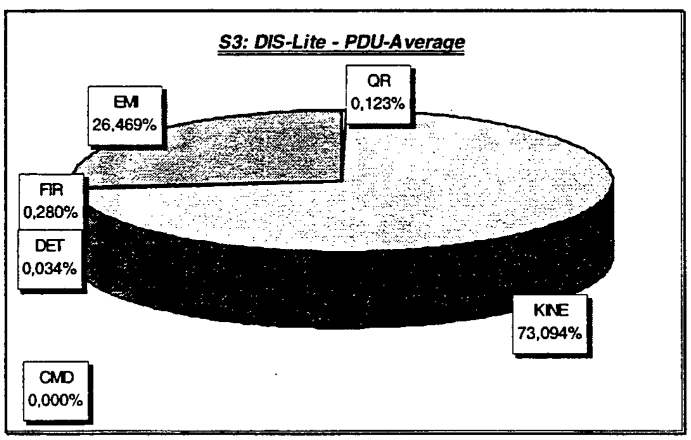


Fig. 6-49 S3- DIS-Lite PDU-Percentage

Quantitatively, the KINE-PDU's, which convey dynamic information about the entity, transfer most of the data to be exchanged. These PDU's are supported by a small number of QR-PDU's, which contain the rest of the entity state information, the relatively static information.

The emission information has the second highest count, accounting for about a quarter of the transferred data packages.

For each launched missile, a FIR- and a DET-PDU's are sent to inform the partner about the new or removed entity.

The percentage of the EMI- and KINE-PDU's are equivalent to that of scenario S2.

6.4.5.1.2.3 Dasa-Protocol

6.4.5.1.2.3.1 Bandwidth

6.4.5.1.2.3.1.1 Bandwidth Usage

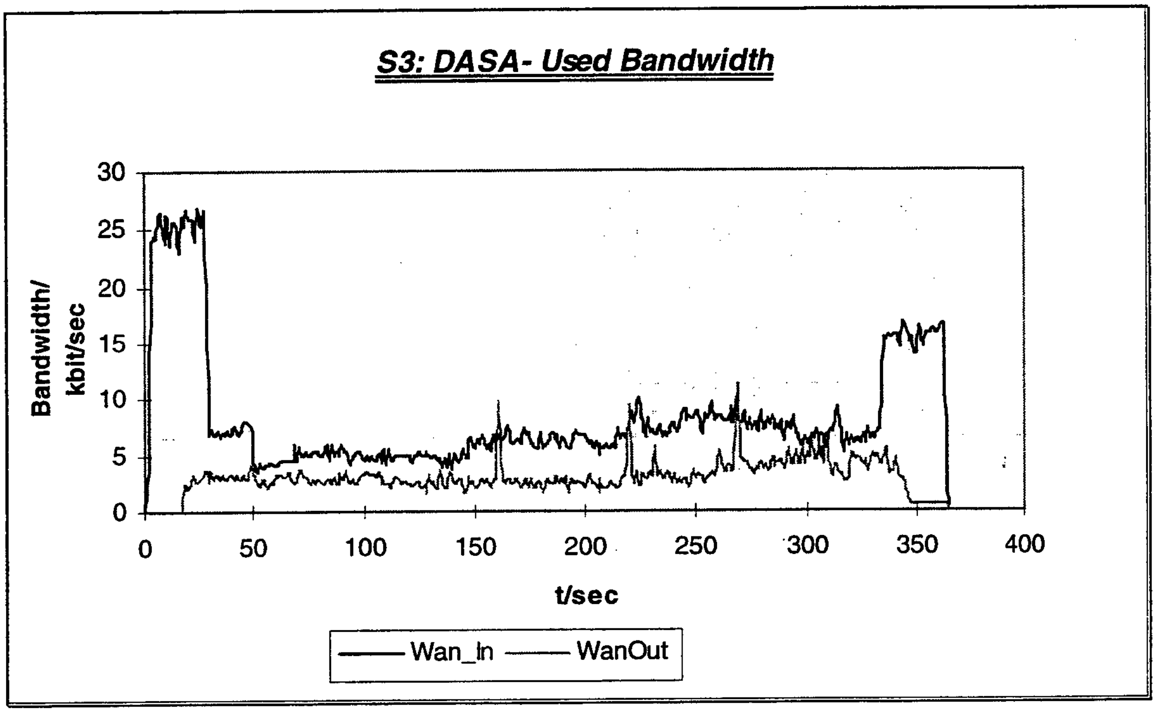


Fig. 6-50 S3- Dasa- Used Bandwidth

The approach and combat phases are not obvious when using the Dasa-Protocol. Overall, a scenario with the complexity of S3 needs a bandwidth of 3 to 10 kbit/sec.

The very high bandwidth value at the beginning of the run on the input line is due to initialization problems. During this period the Dasa-simulation was not active. After activation the Dasa-simulation, the input value drops to a reasonable level. After about t = 50 seconds, the simulation bandwidth is completely stable.

At t = 330 seconds, a AFRL-aircraft goes into a tailspin after being hit by a missile. The tailspin causes an increase in required bandwidth due to its rapid angular changes. In effect, it doubles the bandwidth required and could cause problems if bandwidth limitations are exceeded.

6.4.5.1.2.3.1.2 Bandwidth as a function of the number of entities

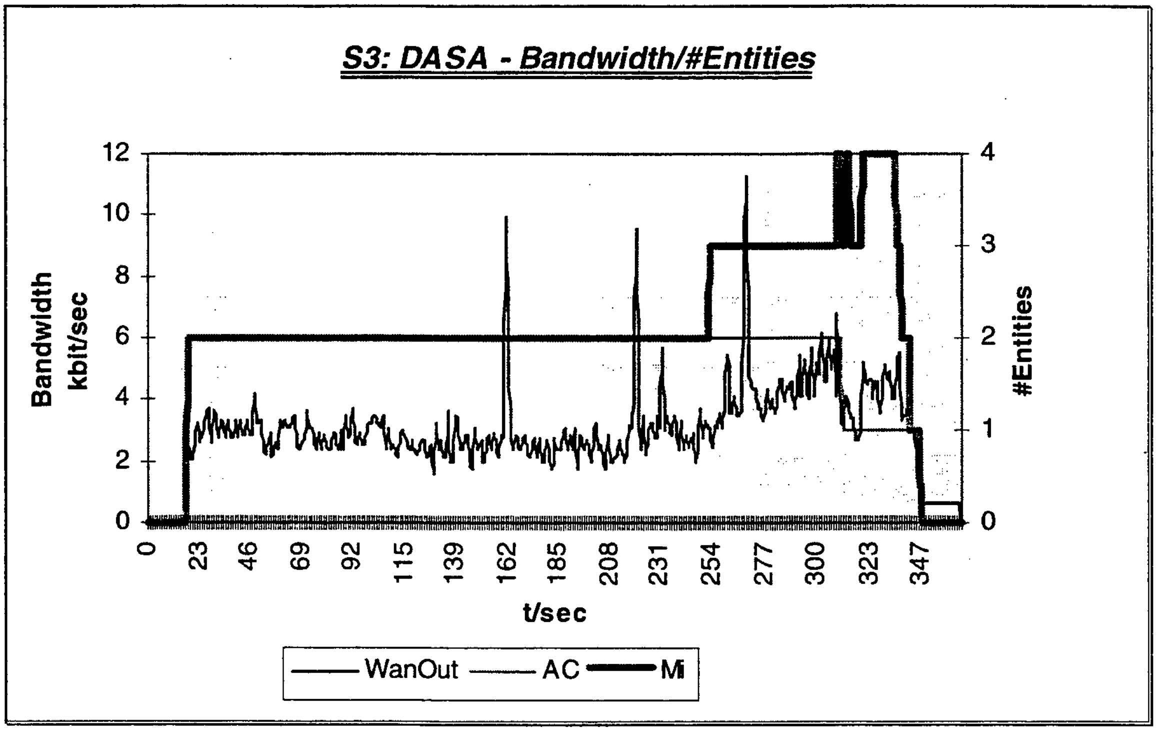


Fig. 6-51 S3- Dasa- Used Bandwidth/#Entities

During the two entity approach phase, a bandwidth of 2 to 4 kbit/sec is needed.

The combat phase starts with the launch of one missile. Later, an additional two missiles are launched. The bandwidth usage slowly increases to 6 kbit/sec to handle 4 active entities (2 AC and 2 MI).

From t = 300 seconds on, after a Dasa-aircraft launched a missile and before it was killed, the number of active entities drops for a short period of time to three (1 AC + 2 MI). The second aircraft then launched another missile. So, the number of active missiles is three and the number of active entities is 4 (1 AC + 2 MI). Comparing the 2 AC + 2 MI case to the 1 AC + 3 MI case, it appears that an aircraft has a greater influence on bandwidth than a missile.

6.4.5.1.2.3.2 PDU-Statistics

6.4.5.1.2.3.2.1 Number of PDU's as a Function of the Number of Entities

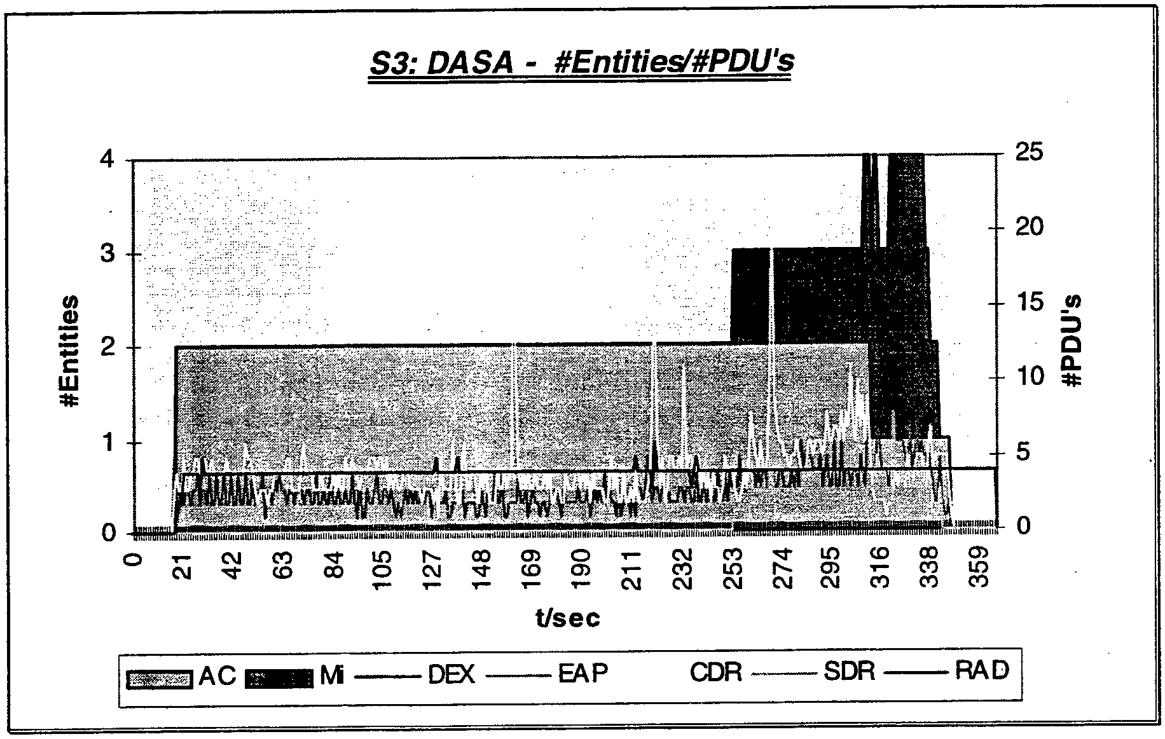


Fig. 6-52 S3- Dasa- #Entities/#PDU's

At the moment of missile activation some SDR-PDU's are sent to handle missile information exchange. Additionally, the increase in the number of CDR-PDU's is the result of a of missile avoidance maneuver by at least one of the Dasa-aircraft. The eventual decrease in the number of CDR-PDU's is a result of the destruction of the Dasa-aircraft.

The figure also shows that the number of transmitted RAD- and EAP-PDU's are not effected by the agility of the entity. It also shows that the number of EAP-PDU's increase with the number of active entities.

6.4.5.1.2.3.2.2 Assignment of PDU-Types over one Complete Run

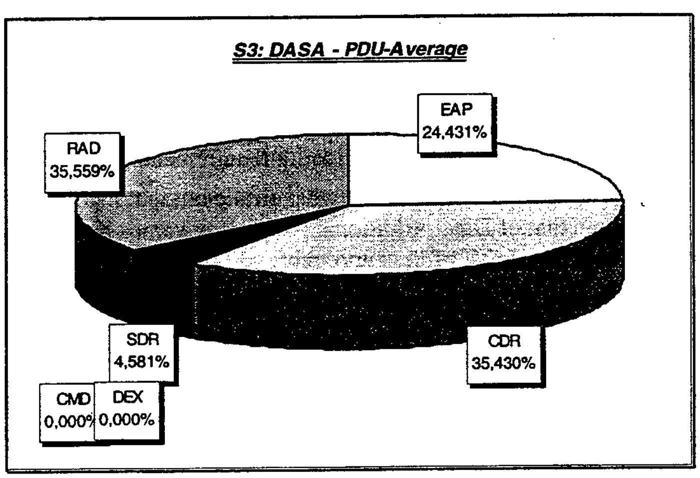


Fig. 6-53 S3- Dasa PDU-Percentage

Fig. 6-53 shows that there is a good balance in the number of PDU's sent. When these percentages are compared to those of scenario S2 (which was a much simpler scenario) we find that the percentage of CDR-PDU's is the same, the percentage of RAD-PDU's has doubled as a result of a higher number of networked entities and the percentages of EAP- and SDR-PDU's has decreased slightly.

6.4.5.1.2.4 Protocol Comparison

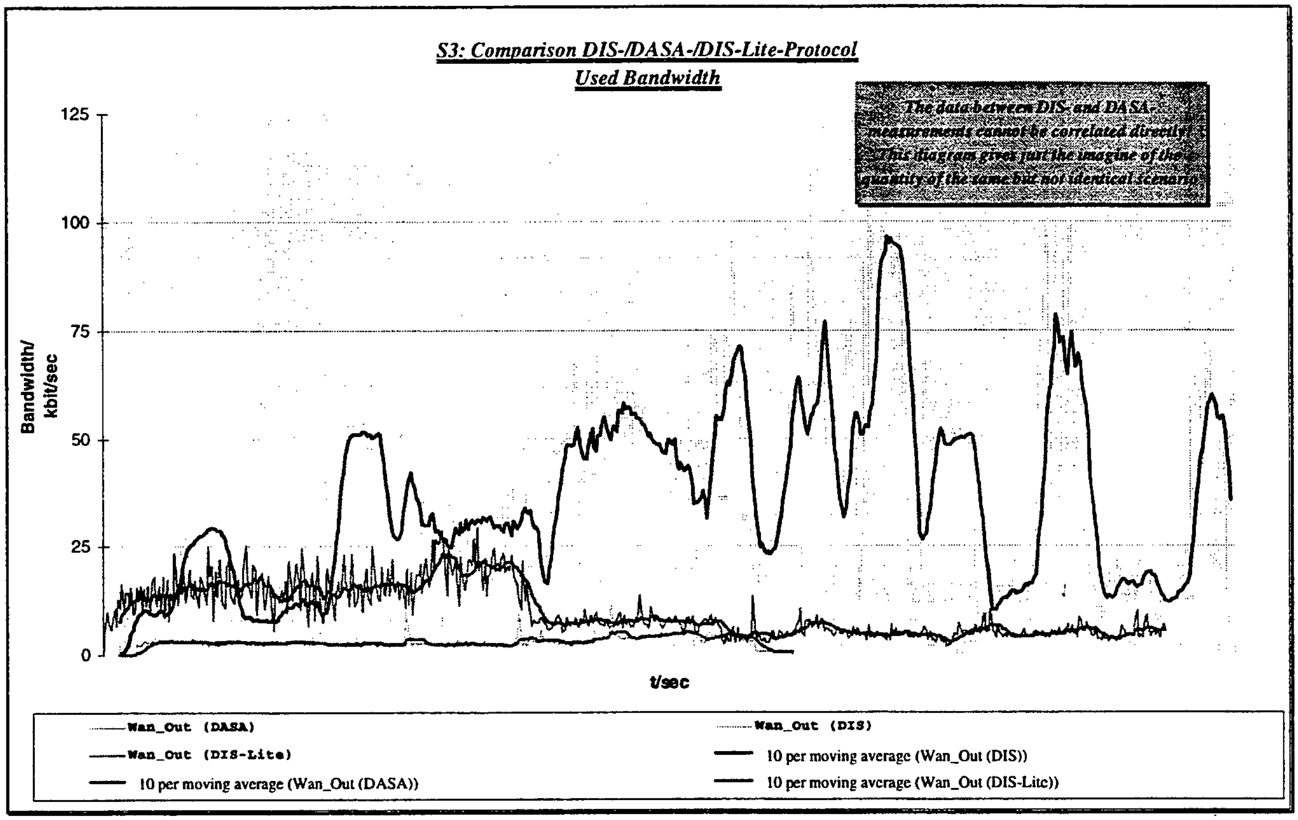


Fig. 6-54 S3 Protocol Comparison

The diagram above compares the bandwidth used by each protocol during scenario S3. The graphs are not directly comparable since the pilots learned from each run and changed their tactics for the next run. However, the plots do give a relative idea of how the average bandwidths required by each protocol would compare. For the analysis, runs with similar complexity were chosen, especially where the number of entities were concerned. The runs were not identical but the scenario and its complexity were the same.

To get a better idea of the values, a 10 per. moving average was calculated for each recorded line.

Notice that the DIS-Protocol is erratic and has the highest bandwidth requirements, with maximum averaged rates of up to 90 kbit/sec and a measured peak bandwidth requirements out to 120 kbit/sec.

Notice also, that the DIS-Lite-protocol is also somewhat erratic but that its bandwidth requirements, up to 25 kbit/sec, are much lower than that of DIS. Additionally, the peak values have been reduced greatly as compared to DIS. Also notice that the second half of the curve represents only one aircraft.

The Dasa-Protocol shows a smoother behavior (less variation between peaks and valleys) and a lower bandwidth requirement at less than 10 kbit/sec for the averaged line. Again, the averaged line shows the required bandwidth for the Dasa-Protocol to be one third that of the DIS-Lite-protocol's.

All measurements depict a low datarate during the approach phases and a steady increase in required bandwidth when missiles are added to the scenario during combat phase.

Protocol	average bandwidth need	peak bandwidth need
DIS	<90 kbit/sec	<120 kbit/sec
DIS-Lite	<20 kbit/sec	<30 kbit/sec
Dasa	<6kbit/sec	<10kbit/sec

6.4.5.1.3 Scenario 4: 4 v 2 + 2 Combat

In this scenario, two hostile forces were simulated. Each side consisted of two manned and 2 digital aircraft. In this scenario, Dasa fielded 2 manned fighters and 2 digital bombers and AFRL fielded 2 manned and 2 digital fighters. All simulated aircraft are equipped with a complete weapons system.

The objective of this scenario is to prevent the hostile force from entering the defender's territory by using MRMs, SRMs and/or the GUN.

6.4.5.1.3.1 DIS-Protocol

6.4.5.1.3.1.1 Bandwidth

6.4.5.1.3.1.1.1 Bandwidth Usage

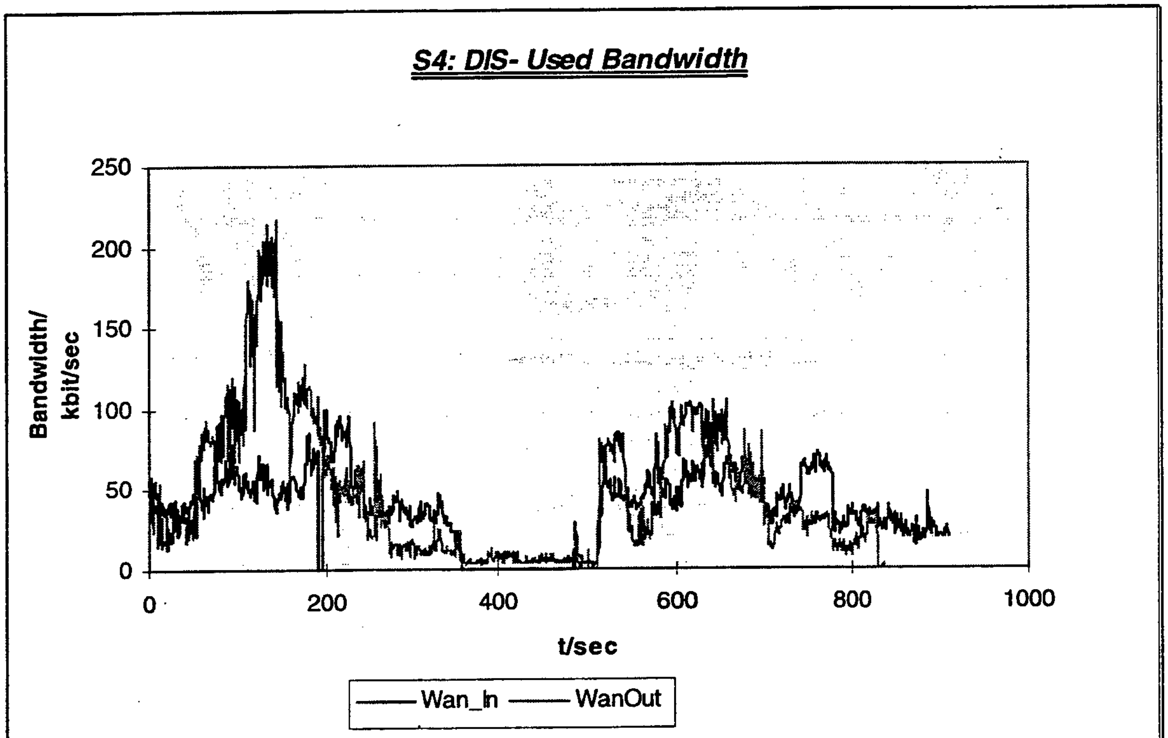


Fig. 6-55 S4- DIS- Used Bandwidth

In the middle of the diagram (t = 500 seconds) the scenario was restarted, so actually two runs of scenario S4 will be discussed within this and the following paragraphs.

Scenario S4 required a bandwidth of up to 200 kbit/sec in the first run and up to 100kbit/sec in the second. This shows the influence different situations have on bandwidth requirements for a more complex scenario. This diagram shows how different tactics can effect the bandwidth requirements. As can be seen, the second run requires about half the bandwidth of the first run even thought the two runs used the same scenario (same number and type of entities and complexity). Even in the first run the different tactics between the Dasa- and the AFRL-forces has the same influence because the Dasa-simulation needs two times the datarate of the AFRL-

simulation. This is not caused by the used CGT (Computer Generated Targets) because the identical scenario with the same complexity causes in the second run just the half of bandwidth need for the Dasa-simulation.

The loss of the input line at t = 200 seconds seems to have been caused by a failing connection line or router because a system reset would have resulted in a new approach phase. However, the input line (Wan_In) in the diagram shows no real break in its behavior. Normally these dropouts can be covered by the protocols.

6.4.5.1.3.1.1.2 Bandwidth as a function of the number of entities

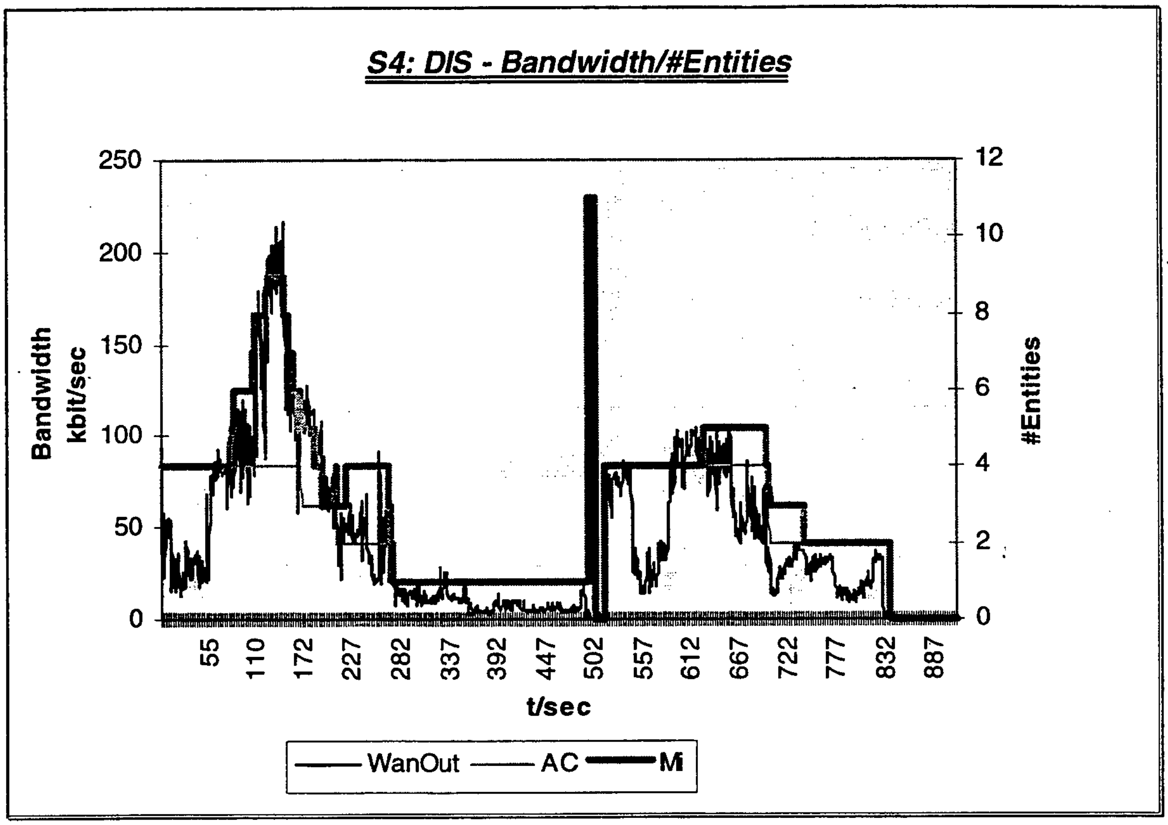


Fig. 6-56 S4- DIS- Used Bandwidth/#Entities

In the diagram, you can see the required bandwidth for the output of the Dasa simulation as a function of the number of active entities.

The diagram shows that the high datarate from the Dasa-simulation in the first run of this scenario was caused by a high number of missiles fired. During this phase, 4 aircraft and 5 missiles are controlled by the Dasa-simulation with the required bandwidth increasing to over 200 kbit/sec. As aircraft are destroyed the required bandwidth slowly decrease.

The second run shows that the 4 aircraft need about 100 kbit/sec during combat engagements. This can also been seen for a short period of time in the first run. The datarate is much lower during the approach phase when there are no combat maneuvers (as at the beginning of run 2).

At the end of the first run, missing scenario management functionality resulted in new CGT's being started and a lot of missile launches by the Dasa-pilots. Normally these procedure effects are not seen in the diagrams when there is only one run visible.

6.4.5.1.3.1.2 PDU-Statistics

6.4.5.1.3.1.2.1 Number of PDU's as a Function of the Number of Entities

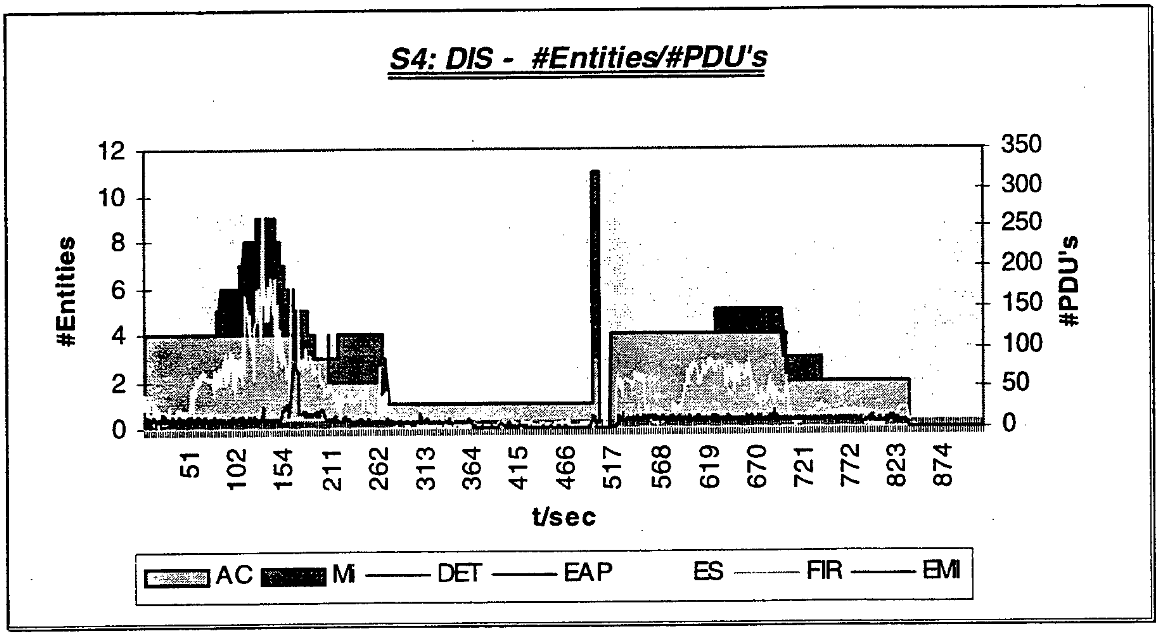


Fig. 6-57 S4- DIS- #Entities/#PDU's

Figure 5-44 shows that the ES-PDU is used to transfer the majority of the simulation data. The figure also shows that the number of ES-PDU's increases dramatically with missiles active.

6.4.5.1.3.1.2.2 Assignment of PDU-Types over one Complete Run

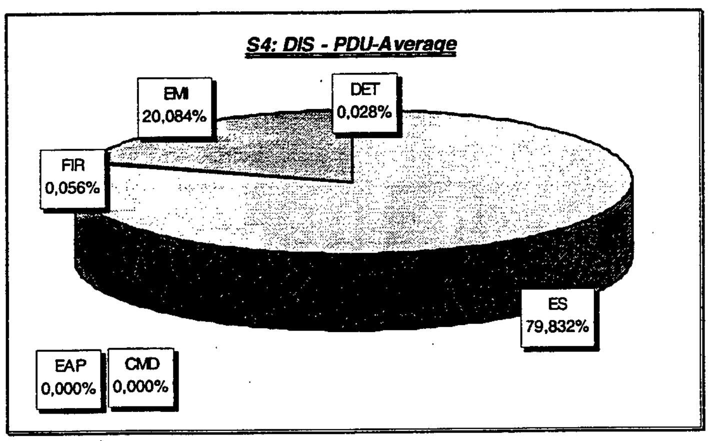


Fig. 6-58 S4- DIS PDU-Percentage

Again, it is obvious that nearly all the information for this scenario is transferred by the ES- and the EMI-PDU.

6.4.5.1.3.2 DIS-Lite-Protocol

6.4.5.1.3.2.1 Bandwidth

6.4.5.1.3.2.1.1 Bandwidth Usage

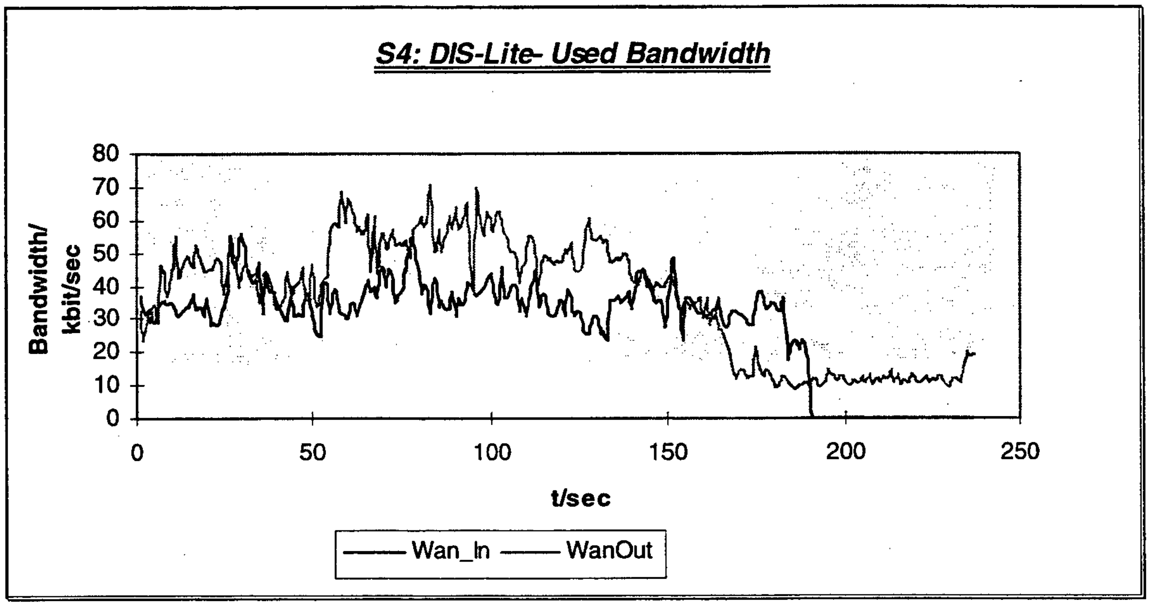


Fig. 6-59 S4- DIS-Lite- Used Bandwidth

The diagram shows the bandwidth usage for scenario S4 using the DIS-Lite-protocol. Overall, the required datarate is 70 kbit/sec with no peaks visible as in previous scenarios.

6.4.5.1.3.2.1.2 Bandwidth as a function of the number of entities

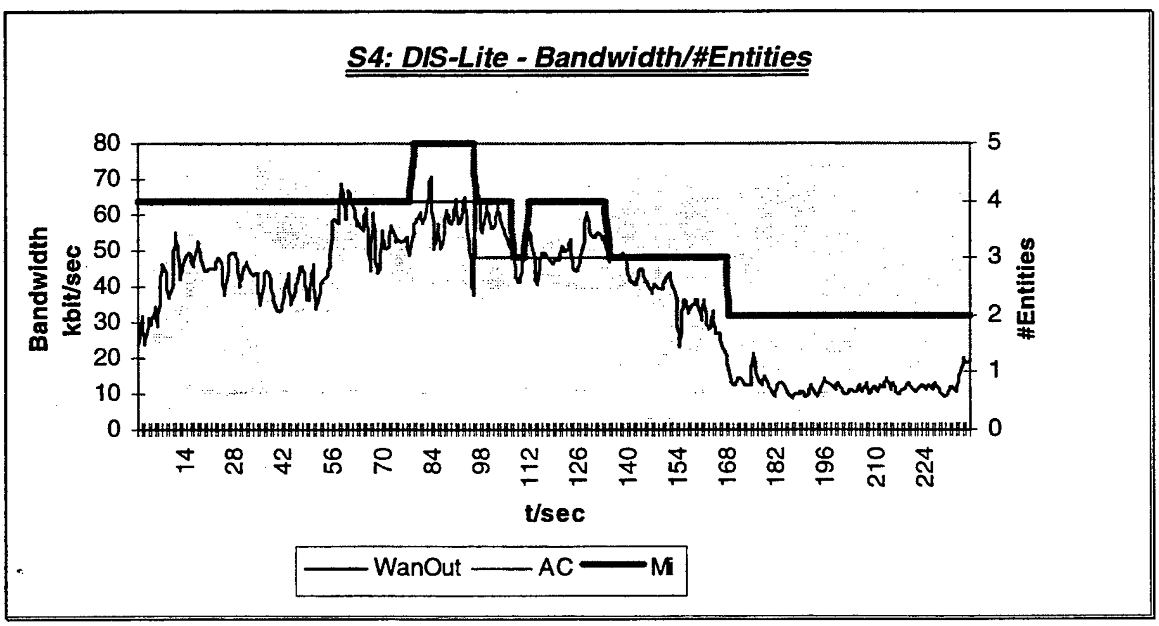


Fig. 6-60 S4- DIS-Lite- Used Bandwidth/#Entities

The diagram shows that during the approach phase, the required bandwidth for the 4 active aircraft was about 50 kbit/sec. Additionally, it shows that in the combat phase with the addition of 1 missile the required bandwidth increases to 70 kbit/sec. At the end of this run, two Dasa aircraft are left and produce a datarate of about 15 kbit/sec which agrees with the datarate seen in scenario S3 for the same number of entities. Also notice the relatively high datarate generated by four entities as compared to that generated by two entities. This run is comparable to the DIS-protocol's second run because of similar weapons usage.

6.4.5.1.3.2.2 PDU-Statistics

6.4.5.1.3.2.2.1 Number of PDU's as a Function of the Number of Entities

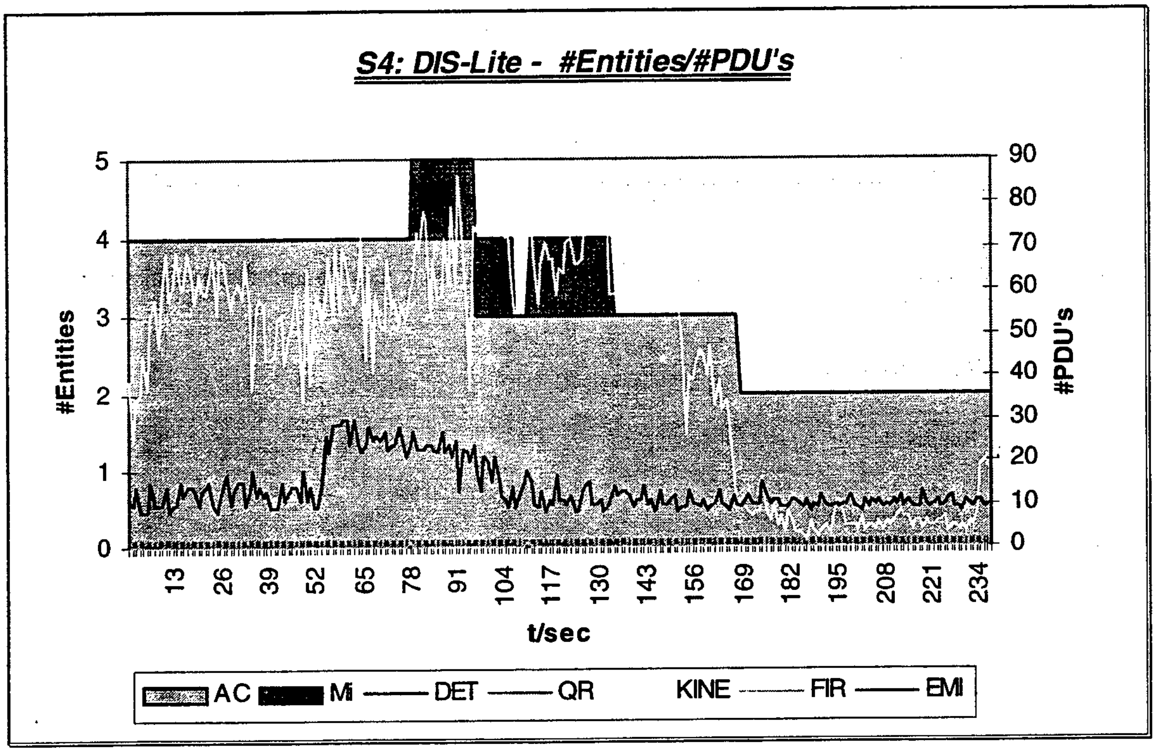


Fig. 6-61 S4- DIS-Lite- #Entities/#PDU's

Strangely, the missile launched at t = 80 seconds does not result in a sudden increase of KINE-PDU's. The number of EMI-PDU's increases at t = 50 seconds from 10 to 20 PDU's/sec because the CGT activated their radar system as late as possible to prevent detection.

6.4.5.1.3.2.2.2 Assignment of PDU-Types over one Complete Run

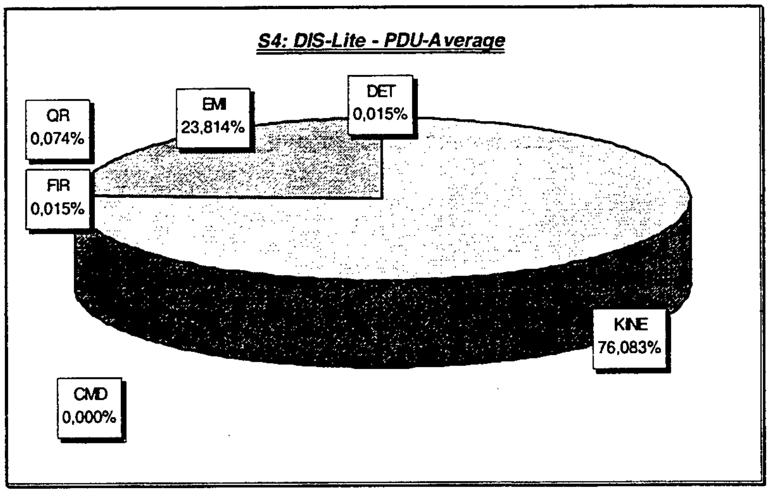


Fig. 6-62 S4- DIS-Lite PDU-Percentage

For this scenario, the DIS-Lite-protocol's KINE- and EMI-PDU's are used to transfer the majority of the exchanged information.

6.4.5.1.3.3 Dasa-Protocol

6.4.5.1.3.3.1 Bandwidth

6.4.5.1.3.3.1.1 Bandwidth Usage

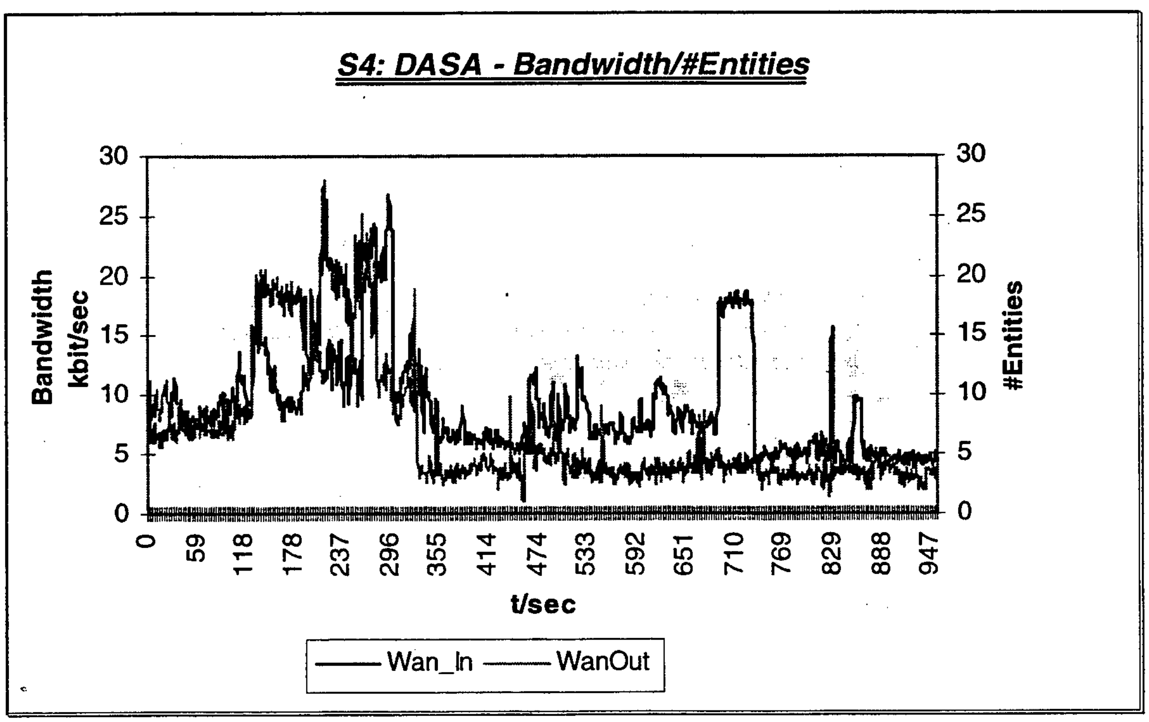


Fig. 6-63 S4- Dasa- Used Bandwidth

For this scenario, the datarate during the approach phase for the four AFRL and DASA aircraft is about 10 kbit/sec and increases to about 30 kbit/sec during the combat phase which ends at about t = 300 seconds. After t = 300 seconds the curve represents a dogfight between the aircraft on the AFRL and Dasa-sides.

Again, the tailspin effect of a destroyed AFRL aircraft is visible about t = 700 seconds on the input line.

6.4.5.1.3.3.1.2 Bandwidth as a function of the number of entities

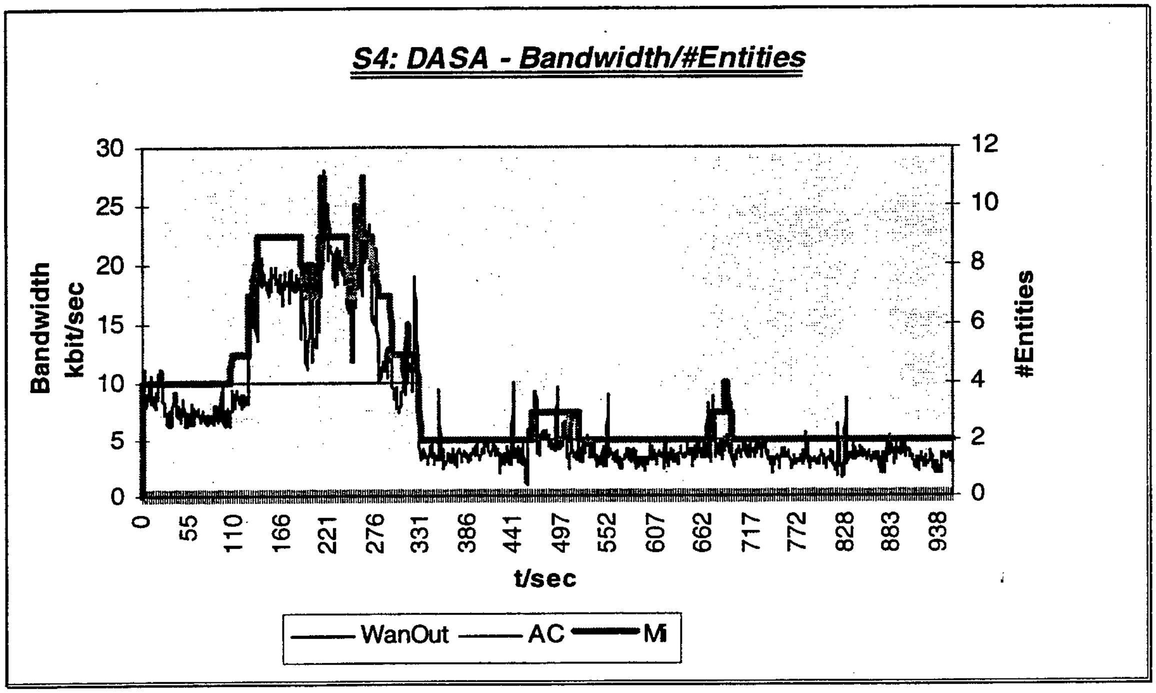


Fig. 6-64 S4- Dasa- Used Bandwidth/#Entities

In additional to the four Dasa controlled aircraft, up to seven missiles get activated at the same time during combat phase. The number of entities and needed datarate drops as two aircraft are destroyed and missiles burn out or detonate.

6.4.5.1.3.3.2 PDU-Statistics

6.4.5.1.3.3.2.1 Number of PDU's as a Function of the Number of Entities

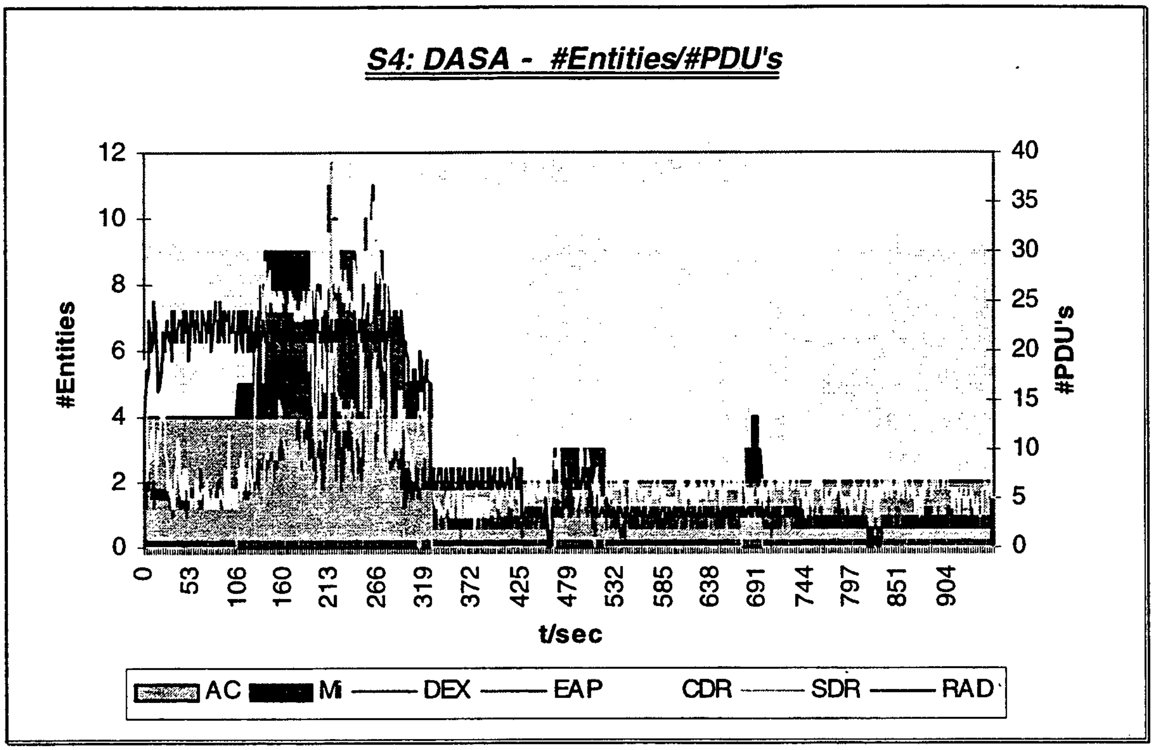


Fig. 6-65 S4- Dasa- #Entities/#PDU's

To cover the necessary information exchange for EW, the number of RAD-PDU's stays at a relatively high level while all 8 aircraft are active. As aircraft are removed from the scenario due to missile hits, the number of RAD-PDU's drops dramatically.

From the figure, you can see the effect that launching missiles has on the number of SDR-PDU's. Additionally, the Dasa aircraft's missile avoidance maneuvers causes the number of CDR-PDU's to increase dramatically. Also, the increase in the number of entities cause a slight increase in the number of EAP-PDU's.

6.4.5.1.3.3.2.2 Assignment of PDU-Types over one Complete Run

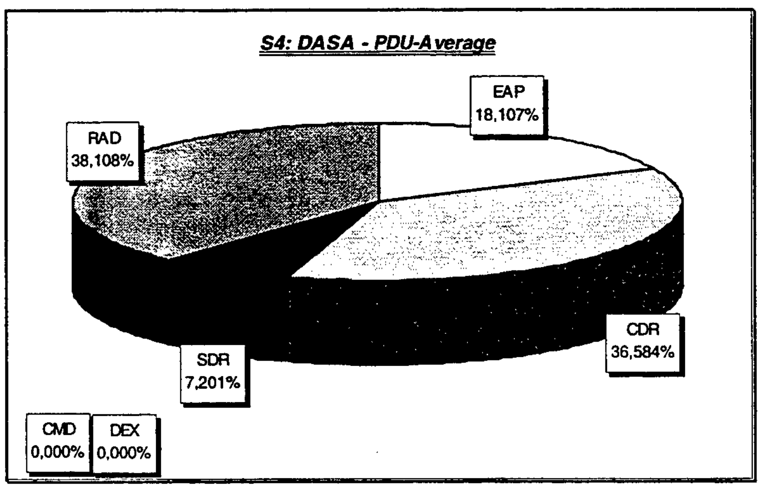


Fig. 6-66 S4- Dasa PDU-Percentage

Again, the CDR-PDU carries about a third of the exchanged information. The percentage of RAD-PDU's used is higher than in the earlier scenarios due to the increased number of aircraft. Also, the percentage of EAP-PDU's is about the same as in scenarios S2 and S3, since it is a function of the number of active entities

The complete information exchange is balanced quite well using these four PDU-types.

6.4.5.1.3.4 Protocol Comparison

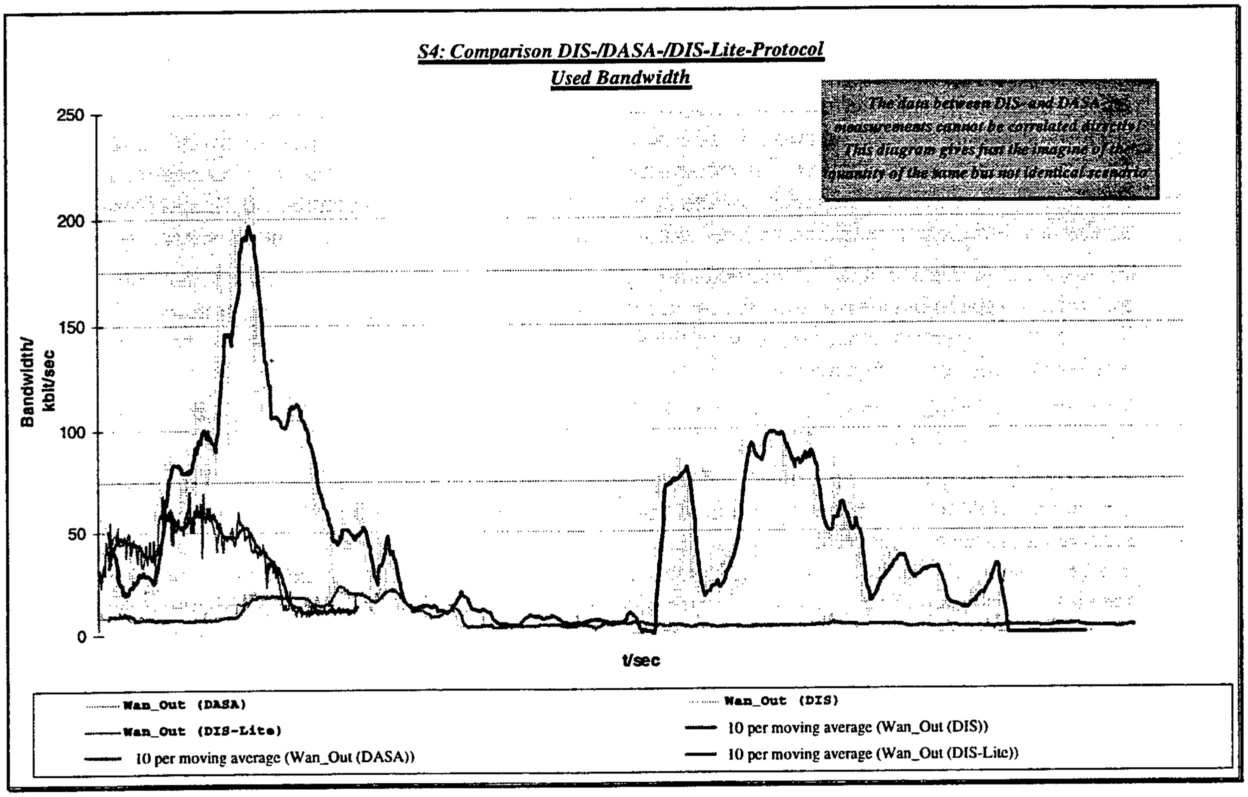


Fig. 6-67 S4 Protocol Comparison

The diagram above compares the bandwidth used by each protocol during scenario S4. The graphs are not directly comparable since the pilots learned from each run and changed their tactics for the next run. However, the plots do give a relative idea of how the average bandwidths required by each protocol would compare. For the analysis, runs with similar complexity were chosen, especially where the number of entities were concerned. The runs were not identical but the scenario and its complexity were the same. The curve for the DIS-Protocol actually represents two runs of the same scenario but with different situations are previously discussed.

To get a better idea of the values, a 10 per. moving average was calculated for each recorded line.

Notice that there was a need for a 200 kbit/sec bandwidth with the ISDN-line providing only 128 kbit overall. Nevertheless, it was still possible to complete the training session, since there were only a few dropouts on the AFRL-site.

Notice again that the DIS-Protocol is erratic and has the highest bandwidth requirements. Notice also, that the DIS-Lite-protocol is also somewhat erratic but that its bandwidth requirements, up to 70 kbit/sec, are lower than that of DIS. The tactical situation and the pilot's actions for the DIS-Lite run are similar to the second run of the DIS-curve. Comparing the DIS- and DIS-Lite-protocols for this type of run shows that the advantage in using DIS-Lite over DIS is not quite as high as in previous runs. However, DIS-Lite still uses only 2/3rd of the DIS datarate .

Again the bandwidth needed by the Dasa-Protocol is still very small even though this run has highest number of active entities (4 aircraft and 7 missiles).

Protocol	*average bandwidth need*	*peak bandwidth need*
DIS	<200 kbit/sec (100kbit/sec)	<220 kbit/sec
DIS-Lite	<65 kbit/sec	<70 kbit/sec
Dasa	<20 kbit/sec	<30 kbit/sec

6.4.5.1.4 Scenario 5: 2 + 2 v 4 Joint Combat

In this scenario two hostile forces were simulated but this time both the AFRL and the Dasa cockpits are performing a joint mission against a hostile force made up of 4 CGT's (Computer Generated Targets). All CGT's are controlled by the Dasa simulation and have a different force ID than the Dasa manned cockpits which has the same force ID as the AFRL cockpits. A communication link between the AFRL and Dasa cockpits was established via a separate telephone line. All aircraft were equipped with a complete weapon system.

In this scenario, Dasa controls 2 manned and 4 digital aircraft and their missiles. AFRL controls two aircraft and their missiles. Because of this, the output line in the diagrams shows a larger datarate than the input line. This scenario extends the requirements of the TRACE program if you survey the Dasa output line which will be discussed in the following chapter.

The objective of this scenario is to prevent the hostile force from entering the defender's territory by using MRMs, SRMs and/or the GUN.

Even though the datarate using the DIS-Lite-protocol was less than for the DIS-Protocol in previous scenarios, it was not possible to setup and run with the DIS-Lite protocol in this scenario. The problem could not be resolved and was not a subject of the TRACE program. It seems that dropouts due to bandwidth limitations, even very small ones, could not be sufficiently recovered by the DIS-Lite protocol and even leads to problems in the simulation computers. Further analysis could help to analyze if there is a problem in the object libraries or the implementation.

6.4.5.1.4.1 DIS-Protocol

6.4.5.1.4.1.1 Bandwidth

6.4.5.1.4.1.1.1 Bandwidth Usage

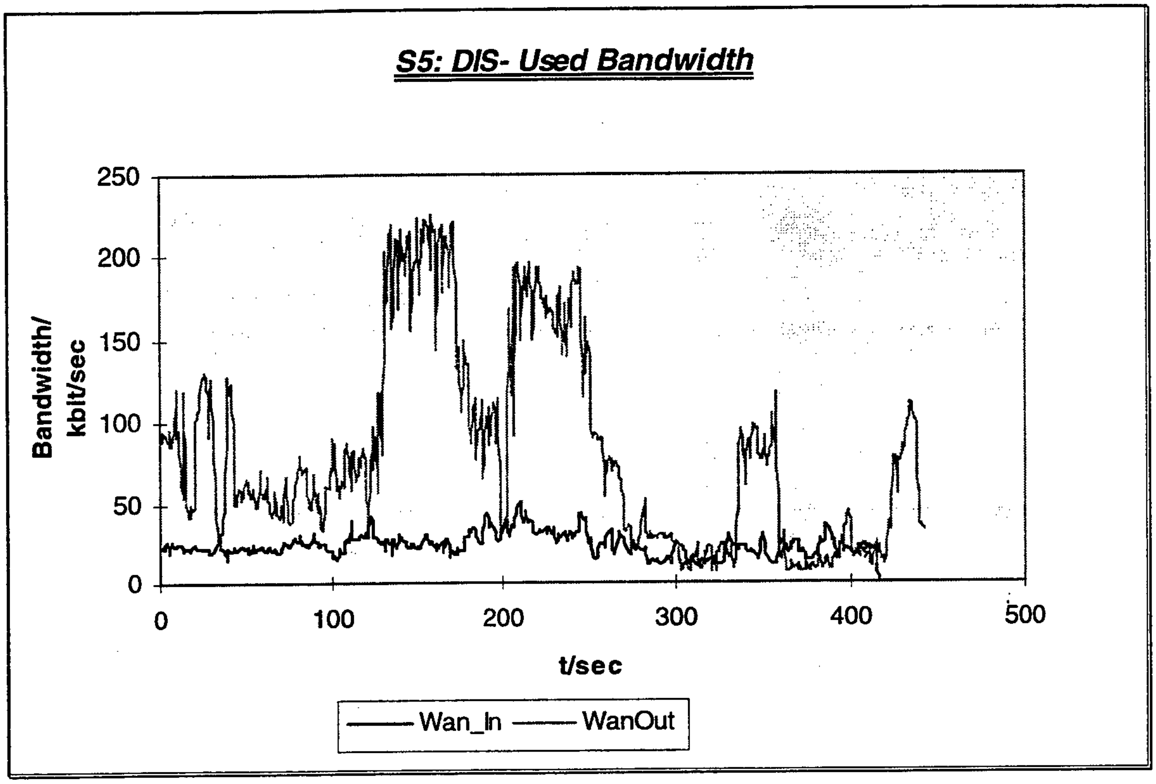


Fig. 6-68 S5- DIS- Used Bandwidth

The WanOut-line in the diagram shows that the required bandwidth for the six Dasa aircraft reaches 220 kbit/sec for this scenario.

6.4.5.1.4.1.1.2 Bandwidth as a function of the number of entities

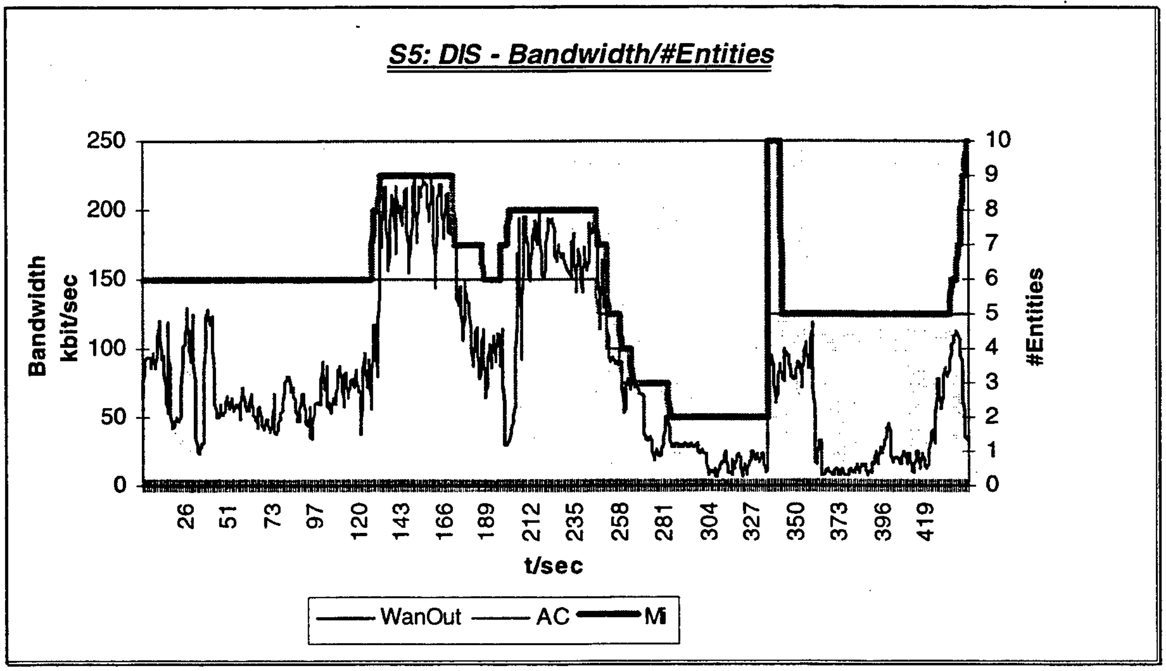


Fig. 6-69 S5- DIS- Used Bandwidth/#Entities

The diagram shows the required bandwidth for the output from the Dasa simulation as a function of the number of active entities. It shows a strong correlation between the number of entities and the datarate. In this instance, firing 3 missiles tripled the datarate. As the missiles burn out the datarate slowly decreases.

From t = 250 seconds on, four of the six Dasa controlled aircraft are destroyed.

At t = 340 seconds, the CGT's at Dasa were restarted and the number of active aircraft at Dasa increased to 5 (1 cockpit plus 4 CGT's). At about the same time, a lot of missiles were fired.

At the end, another group of missiles were launched just prior to a system reset.

6.4.5.1.4.1.2 PDU-Statistics

6.4.5.1.4.1.2.1 Number of PDU's as a Function of the Number of Entities

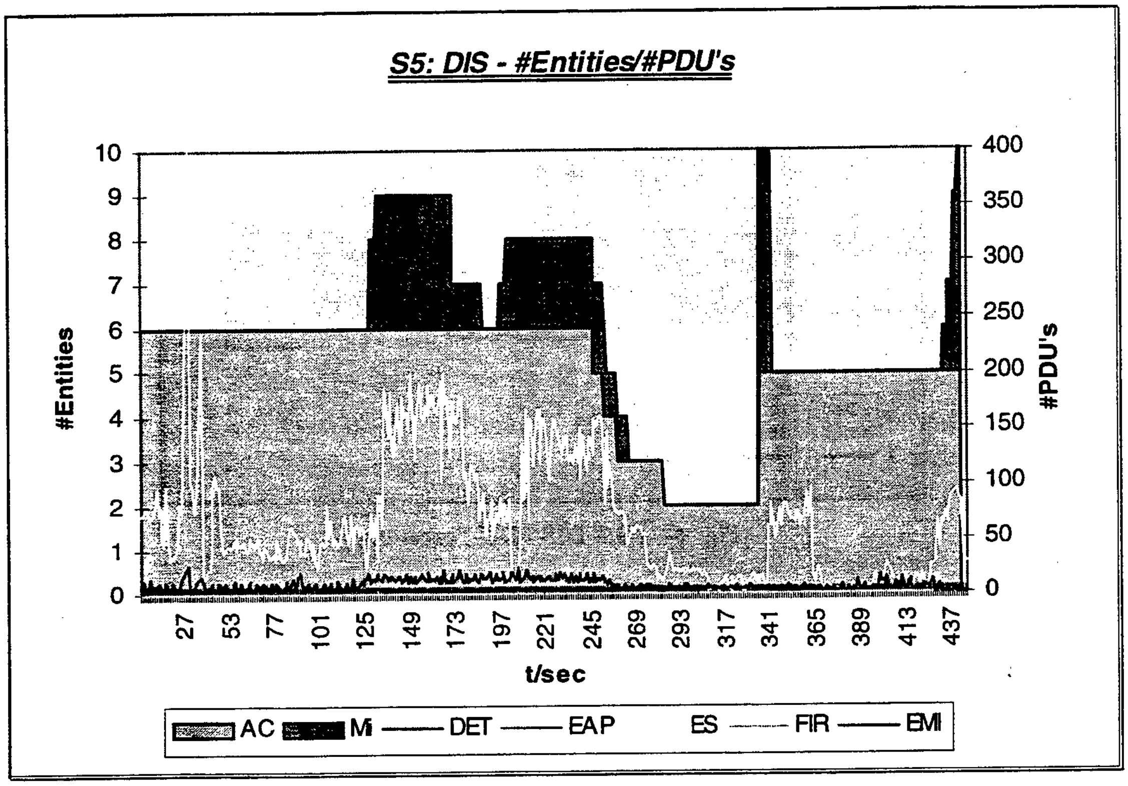


Fig. 6-70 S5- DIS- #Entities/#PDU's

The high number of ES-PDU's at the beginning of the plot are caused by maneuvers for formation bonding before the aircraft begin their approach phase. The figure also shows that launching missiles results in increased numbers of ES-PDU's and EMI-PDU's.

6.4.5.1.4.1.2.2 Assignment of PDU-Types over one Complete Run

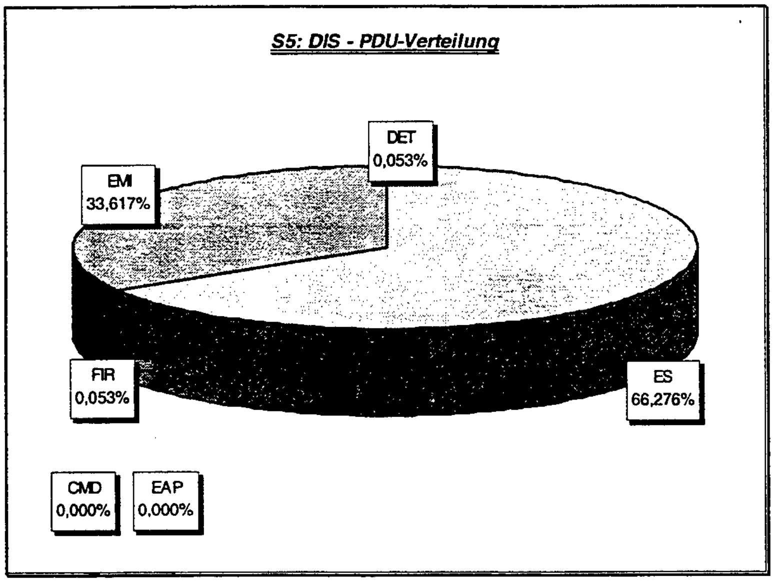


Fig. 6-71 S5- DIS PDU-Percentage

As in previous scenarios, information exchange for this scenario is performed primarily by ES- and EMI-PDU's

6.4.5.1.4.2 Dasa-Protocol

6.4.5.1.4.2.1 Bandwidth

6.4.5.1.4.2.1.1 Bandwidth Usage

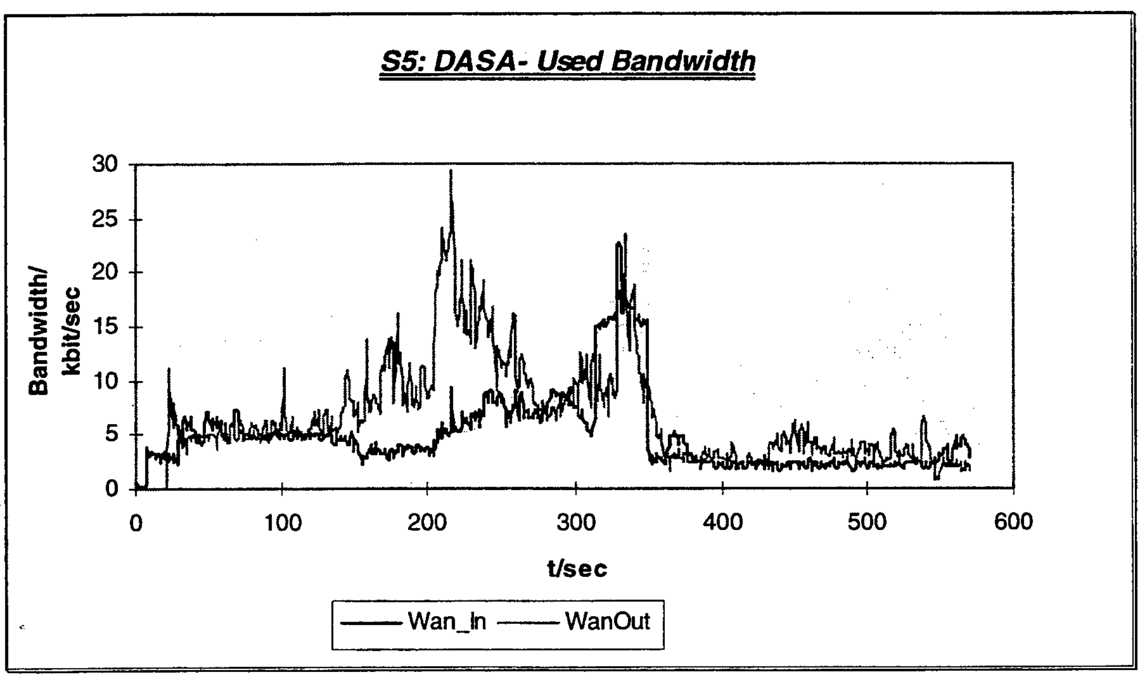


Fig. 6-72 S5- Dasa- Used Bandwidth

This diagram shows the bandwidth required for scenario S5 when using the Dasa protocol. As long as the entities are not maneuvering the datarate stays below 10 kbit/sec. During the combat phase, the Dasa simulation's required bandwidth increases to 25 kbit/sec with a peak of 30 kbit/sec.
The high datarate on the Wan_In line is probably caused by a tailspin from a AFRL aircraft.

6.4.5.1.4.2.1.2 Bandwidth as a function of the number of entities

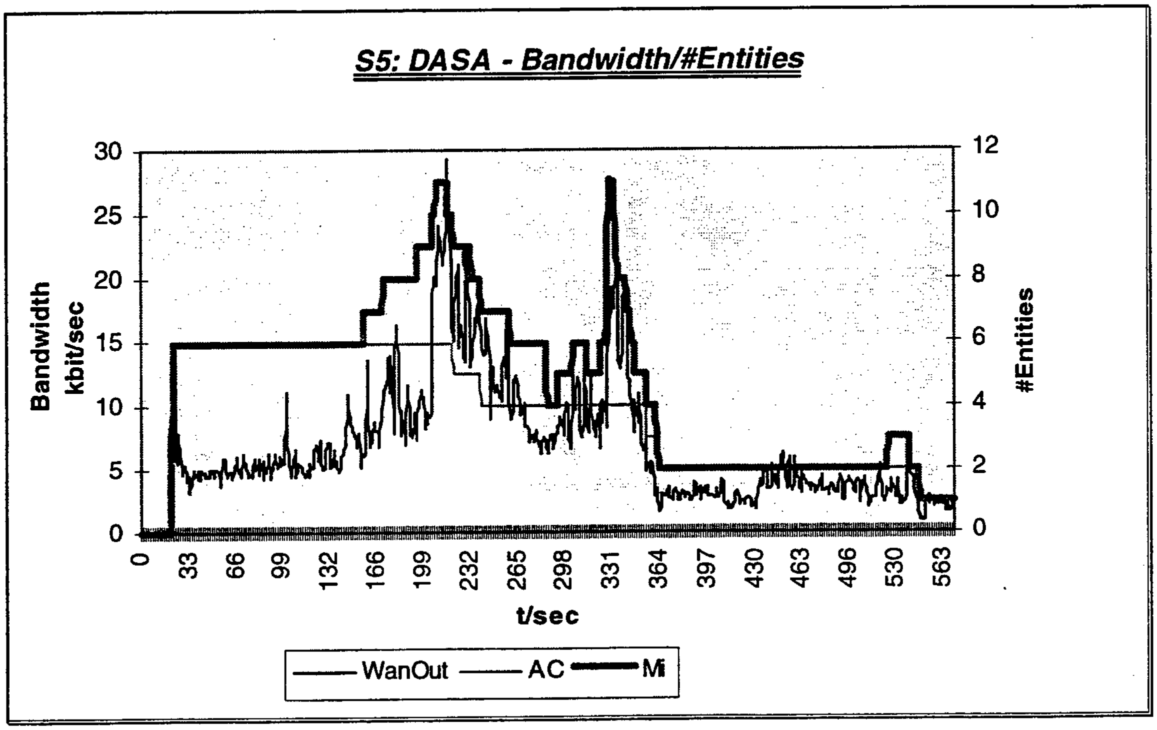


Fig. 6-73 S5- Dasa- Used Bandwidth/#Entities

During this scenario the Dasa simulation controlled up to 11 entities (6 aircraft 5 missiles after t = 160 seconds and 4 aircraft and 7 missiles after t = 320 seconds). The curve for used bandwidth follows the line for the number of controlled entities quite closely.

6.4.5.1.4.2.2 PDU-Statistics

6.4.5.1.4.2.2.1 Number of PDU's as a Function of the Number of Entities

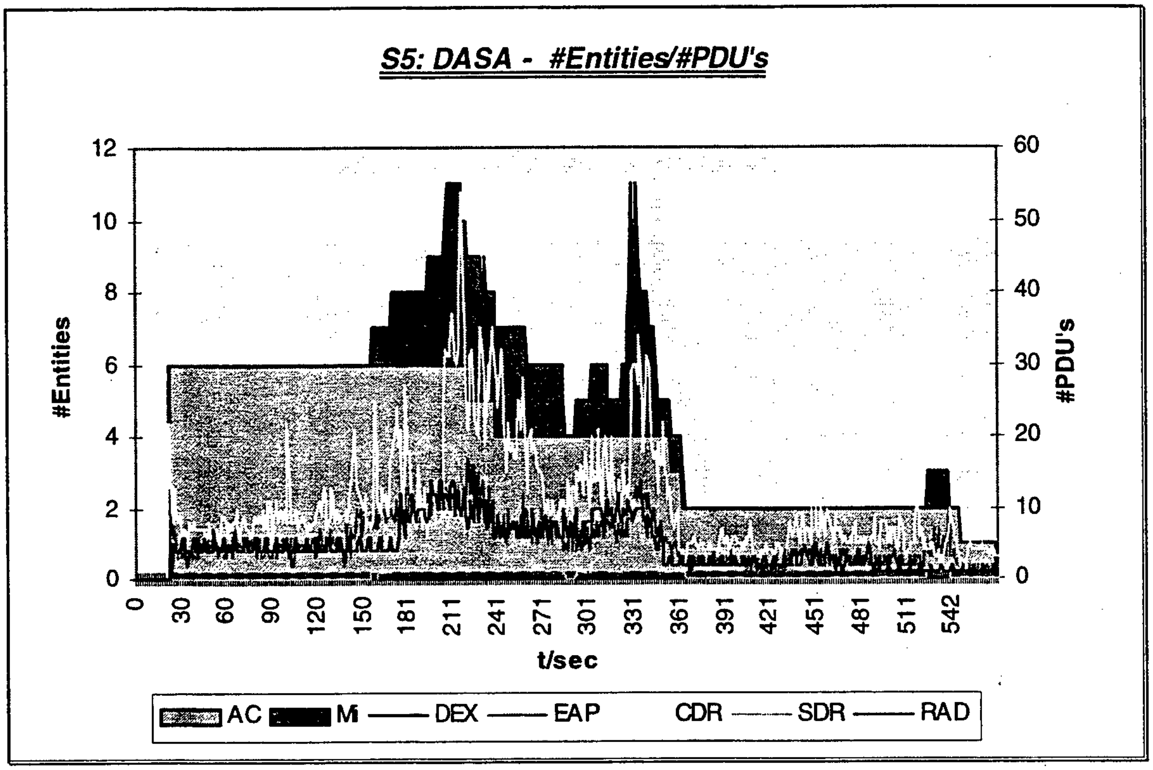


Fig. 6-74 S5- Dasa- #Entities/#PDU's

This diagram shows the types of PDU affected by launching a large number of missiles.

The Dasa simulation uses CDR- and EAP-PDU's to update information about the state of its six aircraft. Furthermore, the number of RAD-PDU's transmitted is still small. This is because radar information between local simulators is only visible locally. Since Dasa controls six aircraft locally, only data effecting the AFRL entities is transmitted.

As in previous scenarios, SDR-PDU's are used to exchange information about the Dasa controlled missiles. Also, due to the increase in the number of entities, the number of EAP- and RAD-PDU's increase.

The high number of CDR-PDU's after t = 200 seconds are the result of an aircraft maneuvering to avoid a missile. The aircraft was subsequently hit by the missile as can be seen by the number of missiles and the number of aircraft decreasing at the same time

6.4.5.1.4.2.2.2 Assignment of PDU-Types over one Complete Run

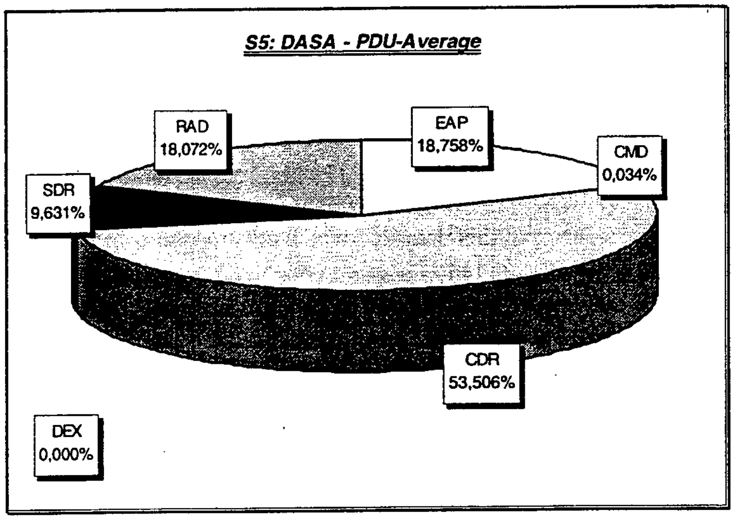


Fig. 6-75 S5- Dasa PDU-Percentage

Because the dispersion of active aircraft was not balanced, the percentage of RAD-PDU's was not as high as it was in previous scenarios. In other words, most of the emission information was exchanged between locally simulated entities and not visible at the output line. Thus, over 50% of the data was exchanged via CDR-PDU's between the Dasa- and the AFRL simulations.

6.4.5.1.4.3 Protocol Comparison

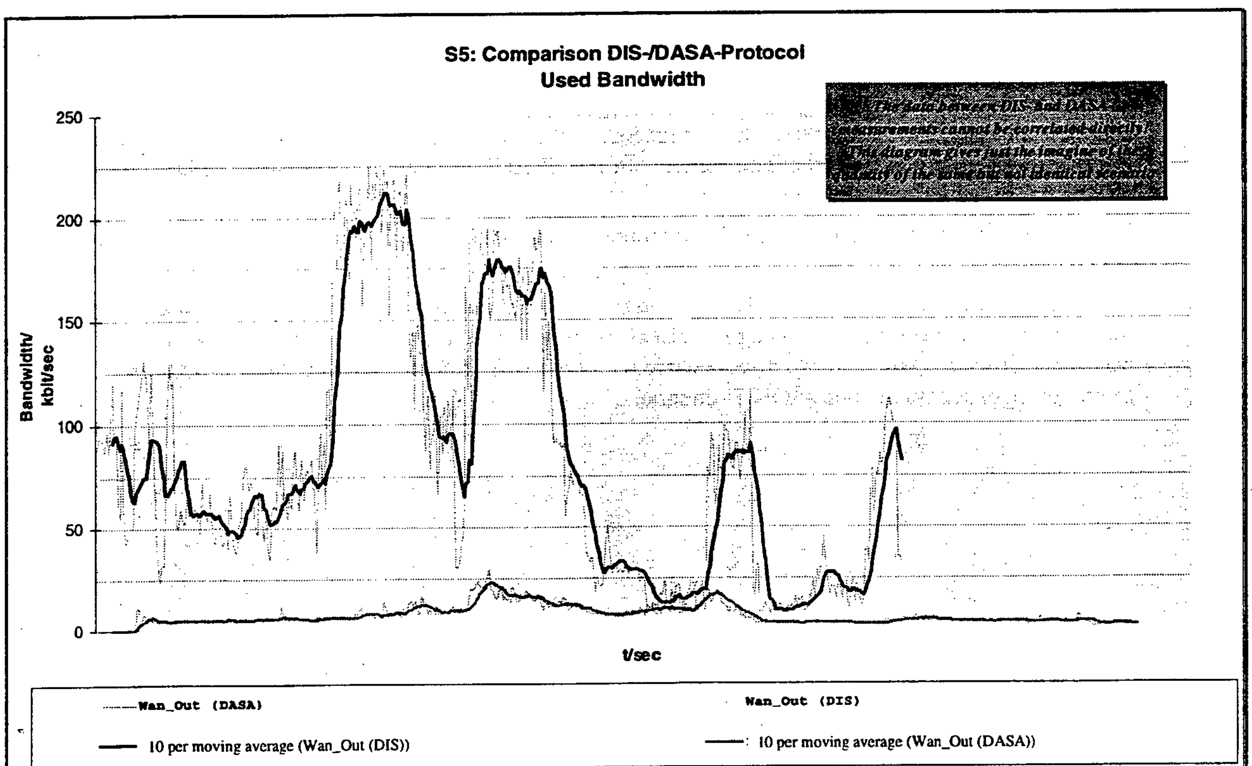


Fig. 6-76 S5 Protocol Comparison

The diagram above compares the bandwidth used by each protocol during scenario S5. The graphs are not directly comparable since the pilots learned from each run and changed their tactics for the next run. However, the plots do give a relative idea of how the average bandwidths required by each protocol would compare. For the analysis, runs with similar complexity were chosen, especially where the number of entities were concerned. The runs were not identical but the scenario and its complexity were the same.

To get a better idea of the values, a 10 per. moving average was calculated for each recorded line.

While the ISDN-line only provided a bandwidth of 128 kbit/sec, the required bandwidth was more that 220 kbit/sec for the DIS-Protocol. This caused data loss at the receiving site. The algorithms used by the DIS-Protocol were unable to recover from this data loss which effected the appearance of the distant entities.

The significant difference of the bandwidths needed by the two protocols is clearly visible. For the DIS-Protocol, the tactical situation and resulting use of weapons causes a high, unpredictable datarate while the Dasa protocol remains at a reasonable level.

Protocol	***average bandwidth need***	***peak bandwidth need***
DIS	<220 kbit/sec (100kbit/sec)	<225 kbit/sec
DIS-Lite		
Dasa	<25 kbit/sec	<30 kbit/sec

6.4.5.1.5 Added Scenario: 2 + 2 v 6 Joint Combat

In this scenario two hostile forces were simulated but, as in scenario S5, both the AFRL and the Dasa manned cockpits are performing a joint mission against a hostile force made up of 6 CGT's (Computer Generated Targets). All CGT's are controlled by the Dasa simulation and have a different force ID than the Dasa manned cockpits which has the same force ID as the AFRL cockpits. A communication link between the AFRL and Dasa cockpits was established via a separate telephone line. All aircraft were equipped with a complete weapon system.

In this scenario, Dasa controls 2 manned and 6 digital aircraft and their missiles. AFRL controls two aircraft and their missiles. Because of this, the output line in the diagrams shows a larger datarate than the input line. For that this scenario extends the requirements of the TRACE program if you survey the Dasa output line which will be discussed in the following section.

The objective is to prevent the hostile force from entering the defenders territory by using MRMs, SRMs and/or the GUN.

This scenario was generated as a result of a request by the pilots for a joint mission against a more powerful force of CGT's in hopes of increasing the effect of training on such an international mission. Unfortunately, it was not possible to setup and run this scenario using the DIS protocol because of the 128 kbit/sec bandwidth limitation imposed by the two ISDN-B-channels.

6.4.5.1.5.1 Bandwidth

6.4.5.1.5.1.1 Bandwidth Usage

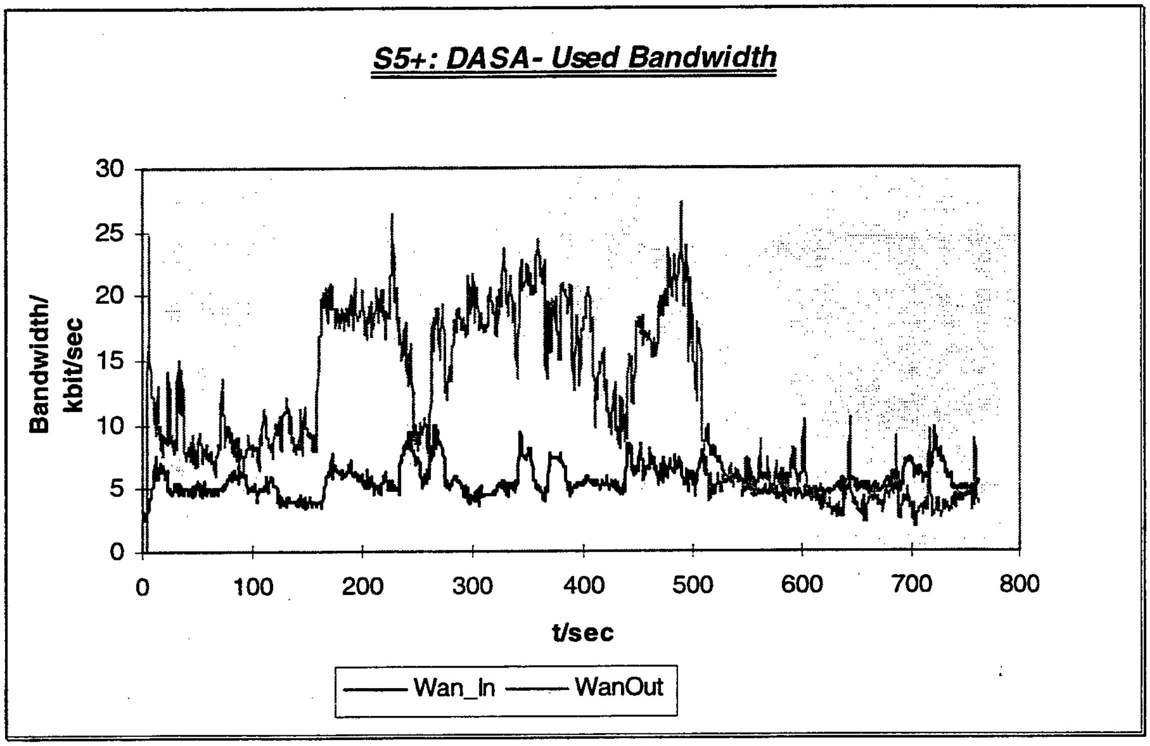


Fig. 6-77 S5+- Dasa- Used Bandwidth

In this scenario, Dasa controls 2 manned and 6 digital aircraft and their associated missiles. AFRL controls two aircraft and their missiles. Because of this, the output line in the diagrams shows a larger datarate than the input line. Of interest here is that the datarate for the 8 Dasa controlled aircraft (without any launched missiles) is just twice the datarate from the 2 AFRL controlled aircraft (even with more emission information sent from AFRL to Dasa).

The WanOut's decreased (after t = 500 seconds) datarate is the result of a reduction in the number of aircraft.

6.4.5.1.5.1.2 Bandwidth as a function of the number of entities

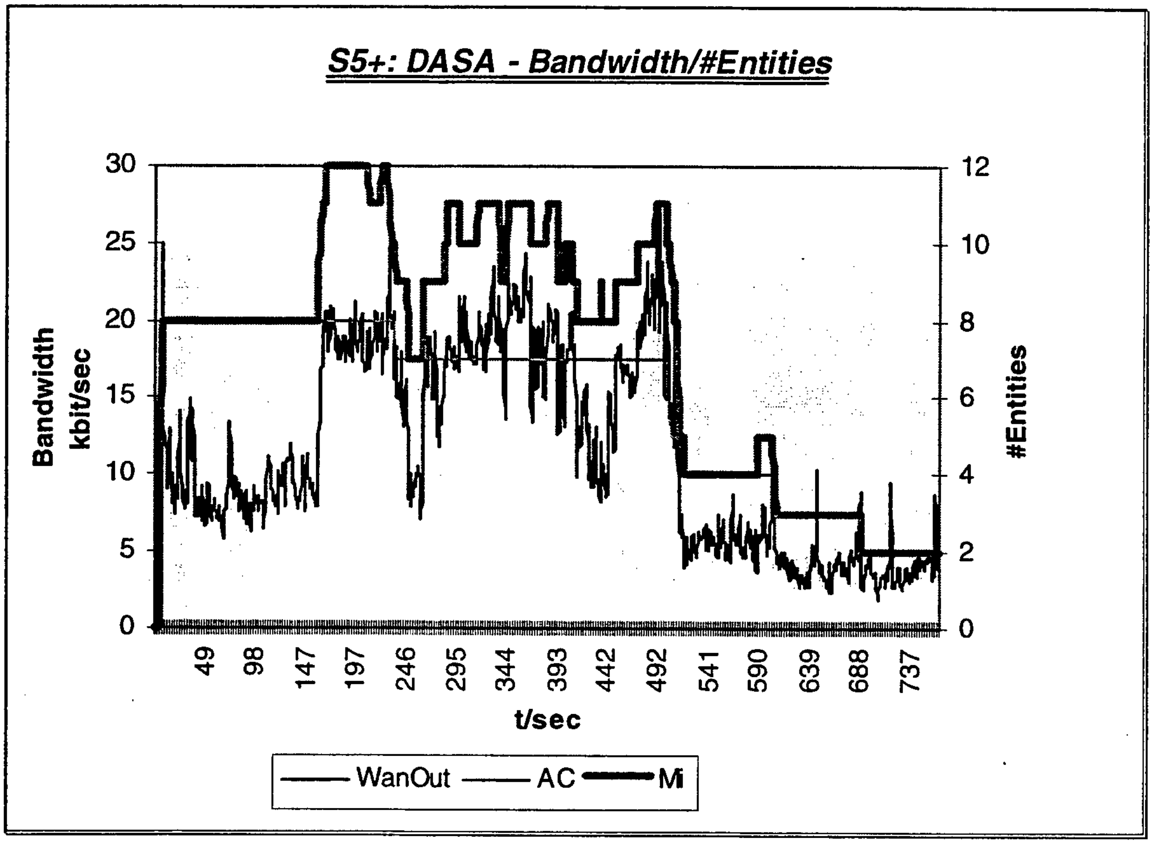


Fig. 6-78 S5+- Dasa- Used Bandwidth /#Entities

The scenario starts with eight local aircraft performing the approach phase. The used datarate increases from 10 to 25 kbit/sec as the combat phase begins. At t = 500 seconds, most of the Dasa controlled aircraft are destroyed and the datarate drops to the value corresponding to that of scenario S4 (S4 had 4 active aircraft).

Up to 12 entities were controlled by the Dasa simulation at the same time and provided for the interconnected scenario.

6.4.5.1.5.2 PDU-Statistics

6.4.5.1.5.2.1 Number of PDU's as a Function of the Number of Entities

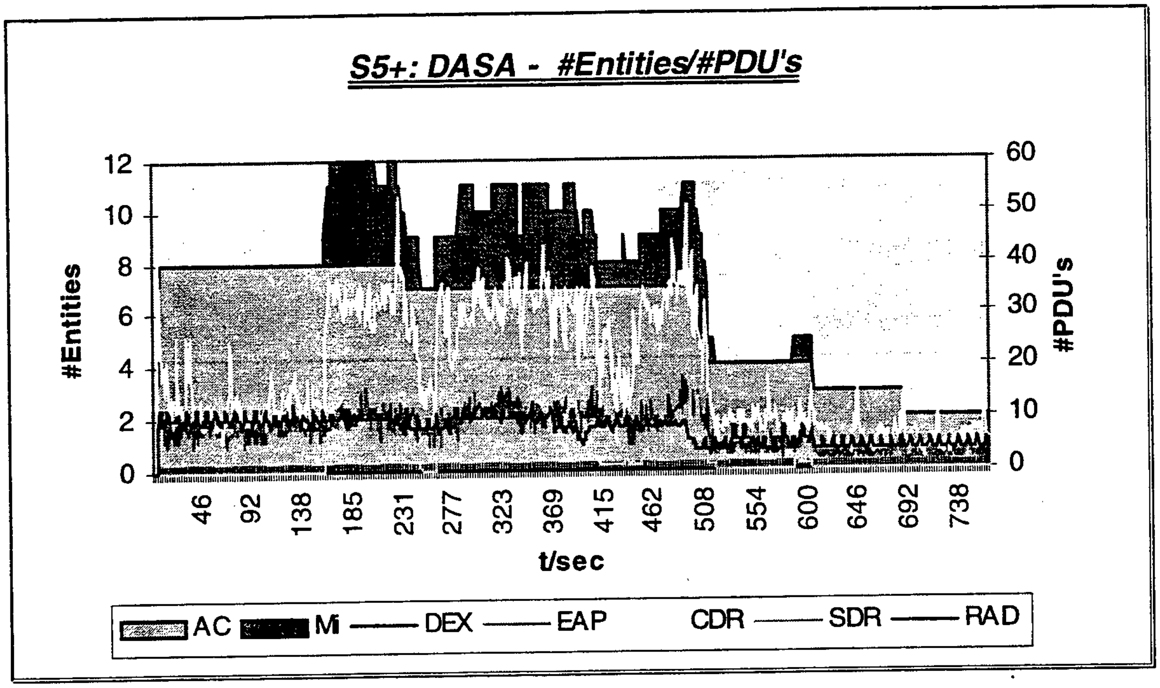


Fig. 6-79 S5+- Dasa- #Entities/#PDU's

The number of RAD-PDU's is still small as in scenarios S2 to S4 because most of the involved entities are simulated locally and the emission information only has to be provided for the 2 distant AFRL controlled aircraft and their missiles.

The diagram shows the effect of missile launches on the amount of SDR-PDU's and the effect of agile maneuvering on the number of CDR-PDU's.

6.4.5.1.5.2.2 Assignment of PDU-Types over one Complete Run

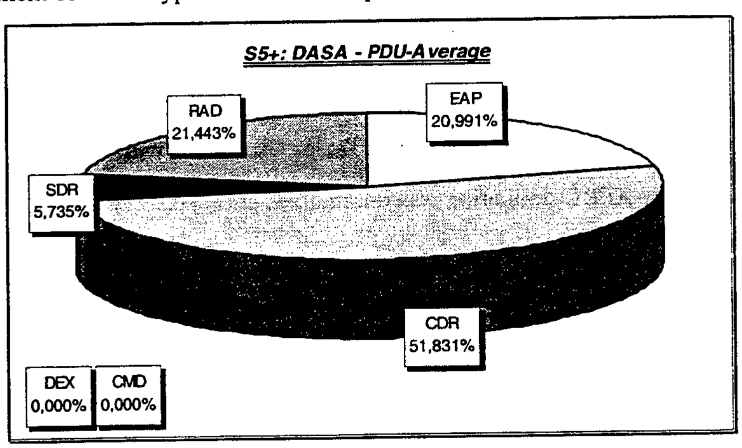


Fig. 6-80 S5+- Dasa PDU-Percentage

As in scenario S5, the unbalanced dispersion of involved entities results in a high percentage of CDR-PDU's. The percentages of the types of PDUs used is in accordance with the analysis of the scenario S5, even thought this scenario is more complex.

6.4.5.1.6 Added Scenario: 1v1v1v1 Combat

This scenario was generated on request of the pilots as a training scenario for high agility maneuvering. Four manned cockpits (2 at AFRL and 2 at Dasa), all hostile, are placed in opposite direction and same distance to an imaginary central point. Each pilot tries to out maneuver and kill a hostile aircraft with either a SRM or GUN. A possible kill will be overwritten by simulation software, but the aircraft must go out of range and re-enters after a short period of time.

For such a scenario, the measurements represent the influence of high agility aircraft maneuvers on the required bandwidth.

This scenario was only performed using the Dasa protocol.

6.4.5.1.6.1 Bandwidth

6.4.5.1.6.1.1 Bandwidth Usage

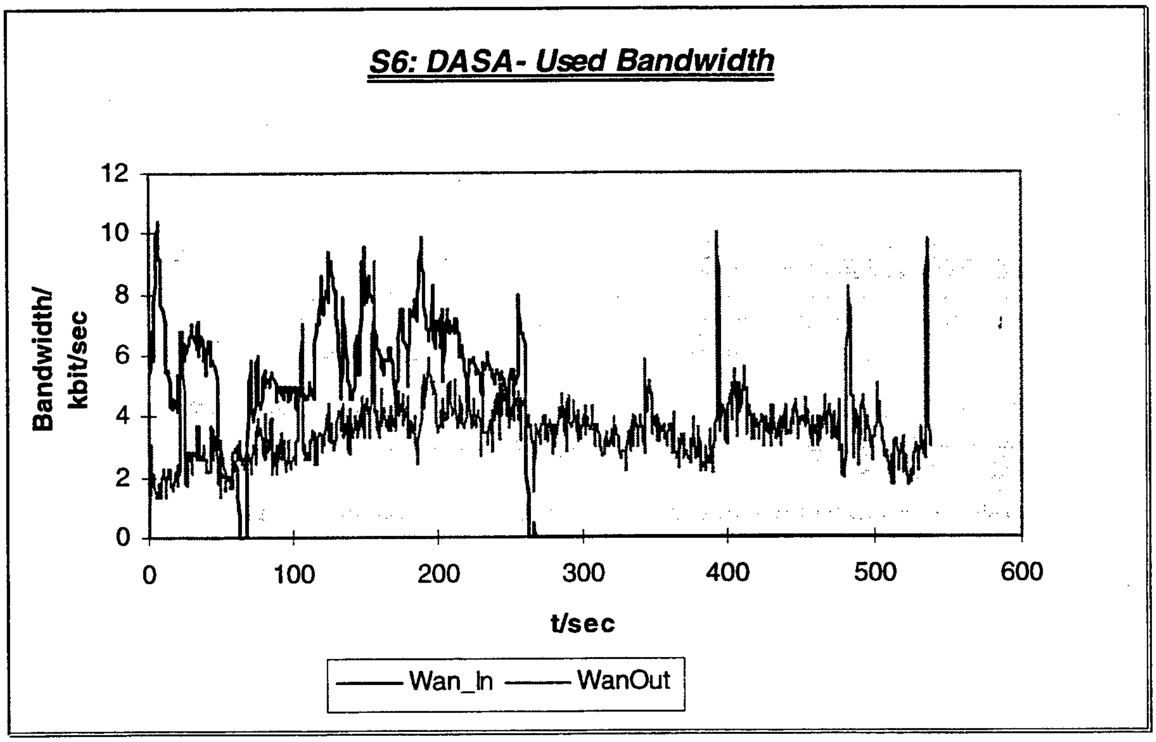


Fig. 6-81 S6- Dasa- Used Bandwidth

Due to many reasons, the AFRL simulation was reinitialized at t = 70 seconds and was removed from the scenario at t = 280 seconds.

The curves represent the datarate for each of the two controlled aircraft and their launched missiles. The datarate is noisier than in previous scenarios when using the Dasa protocol.

6.4.5.1.6.1.2 Bandwidth as a function of the number of entities

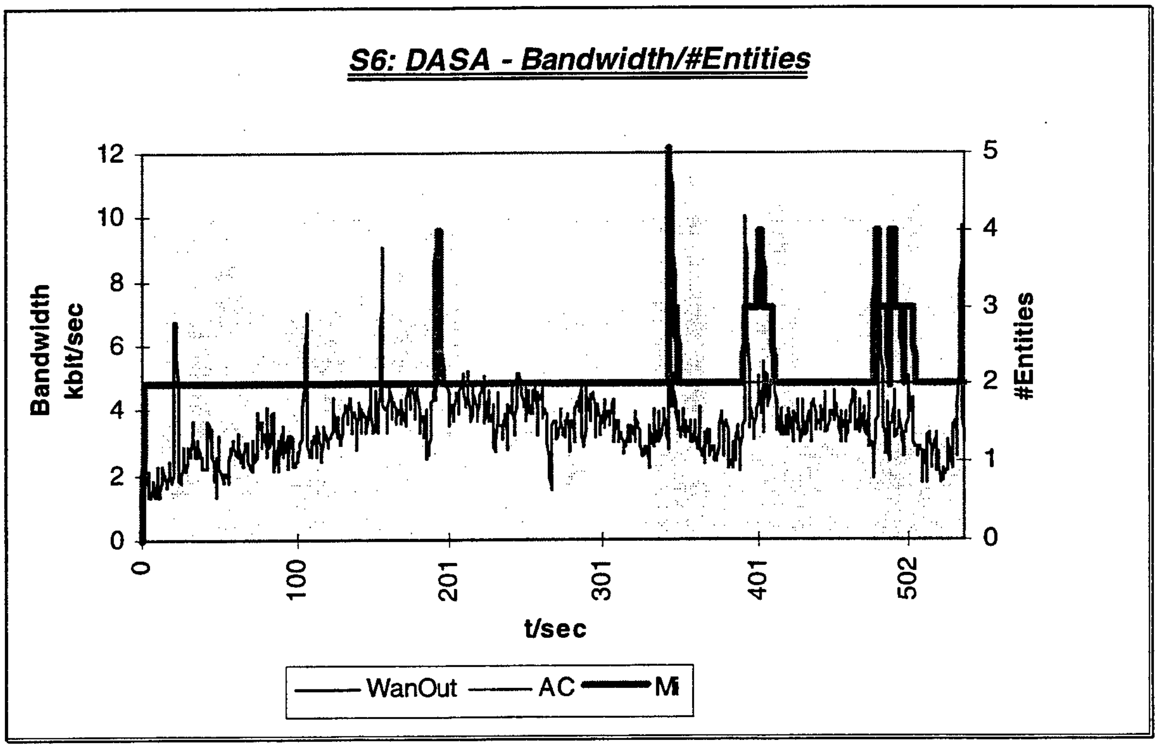


Fig. 6-82 S6- Dasa- Used Bandwidth/#Entities

Because of the simulation's overwrite function, there are always 2 aircraft active even if they have been destroyed.

A bandwidth of 4 kbit/sec with peaks up to 10 kbit/sec is needed for this scenario.

6.4.5.1.6.2 PDU-Statistics

6.4.5.1.6.2.1 Number of PDU's as a Function of the Number of Entities

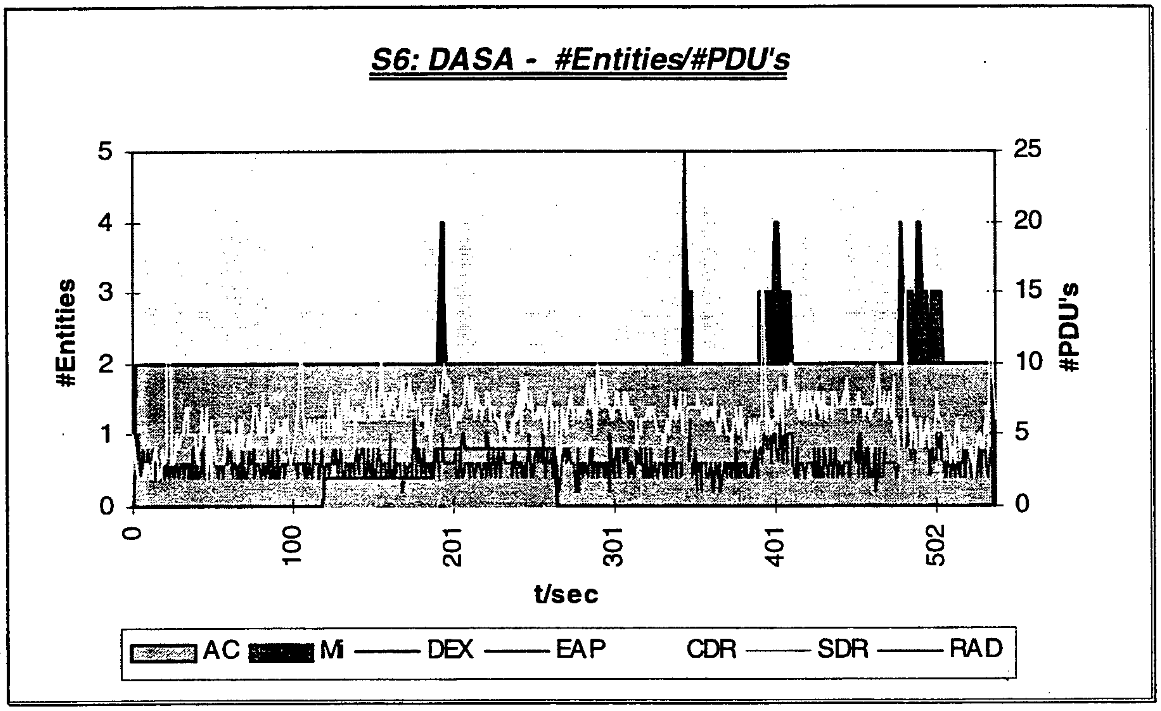


Fig. 6-83 S6- Dasa- #Entities/#PDU's

The peaks in the curve represent the number of CDR-PDU's which can be in comparison with datarate diagrams before correlated with peaks of the used datarate. Additionally, the RAD-PDU curve shows that the radar systems were switched off during the first seconds. As the AFRL simulation was taken out of the scenario at t = 280 seconds, this results in the total absence of RAD-PDUs since emission data not longer needs to be sent to AFRL.

6.4.5.1.6.2.2 Assignment of PDU-Types over one Complete Run

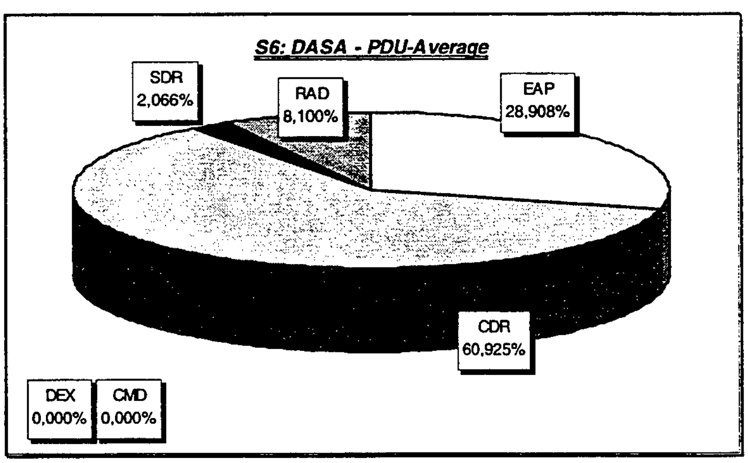


Fig. 6-84 S6- Dasa PDU-Percentage

In this scenario, since only SRMs were allowed to be fired, only a few missiles were launched. This results in a small amount of missile depend information which was exchanged via SDR-PDU's.

The percentage of transmitted RAD-PDU's in this run is relatively low because the AFRL simulation was taken out of the scenario rather early.

6.4.5.2 Scenario Comparison

A protocol's effectiveness is measured by how accurately a receiving site can regenerate the transmitting sites values and by how demanding it is on system resources. While objective measurements can be made using precise positioning which yields theoretical results, the subjective impression of the pilots as the end user is more relevant to system configuration.

During the tests, the pilots could not tell which protocol was being used even if switched during a given scenario. However, if bandwidth limitations imposed by the ISDN connection were exceeded loss of data would result and thus the loss of the ability to regenerate networked aircraft. When this occurred, the training sessions became insufficient, ineffective and inconvenient. The protocol leading to this situation would not be used for further more complex scenarios.

The Fig. 6-85 shows the bandwidth required by all the protocols used for all the scenarios. The data rate is drawn in increments of 50 kbit/sec, approximate usable bandwidth of one ISDN-B-channel. The maximum usable bandwidth defined by the TRACE program was the usable rate of 2 ISDN-B-channels, about 110 kbit/sec.
If the available bandwidth is exceeded, the data to be exchanged will either be sent with some increased latency or be discarded. It is up to the network interface computers (NIC) to handle these situations without loss or damage to data.

Scenarios S2 to S5+ increase in complexity by increasing the number of aircraft involved. All protocols were suitable for scenarios S2 to S4 even when the peak bandwidth value of the DIS-Protocol exceeded the ISDN limitation. Normally, data can be correctly transferred but with some increase in latency which can cause a positioning error higher than the preset one. Such errors would only be seen in the visual system if the aircraft are flying relatively close, in formation or some kind of dogfight.

In scenario S4, the data rate produced using the DIS-Protocol could not be covered by the bandwidth of the 2 ISDN-B-channels. While the training session was completed by the pilots, the preset thresholds were exceeded as expected. If the active entity's position is not precise enough, the correct use of weapons cannot be guaranteed. This can result in such effects as multiple targets in the radar systems, problems with radar detection, or errors in missile hit calculations.
According to the scenario S4 discussion, scenario S5 should cause the DIS-Protocol to exceed the bandwidth limitations, but the training sessions could be completed by the pilots again. Of interest is that the DIS-Protocol has about the same data rate as in the previous scenario even though there are more simultaneously active entities. Because it was not an objective of the TRACE program to study the behavior of the protocols if the bandwidth limitations are exceeded, a closer look could be done in analyzing the reason of the smaller bandwidth need of the DIS-Protocol during scenario S5. An explanation could be the unbalanced dispersion of active entities over the network resulting in less EMI-PDU's to be sent for radar and IR-information exchange. Since DIS-Lite exceeded the bandwidth limitation during setup it could not recover from the data loss, therefore, it could not be used for scenario S5. The incoming data also caused problems in the simulation computers.

In all the scenarios, the datarate produced by the Dasa protocol could have been handled by just one of the two ISDN-B-channels. Scenario S6 represents the data rate of just two very agile aircraft with a small number of missiles. Of interest is the higher average and peak data rate when compared to scenario S2 which also represents the data rate for two less agile aircraft.

For all the protocols, the difference between the peak and average data rates does not increase with the more complex scenarios even though the scenarios cause high average data rates.

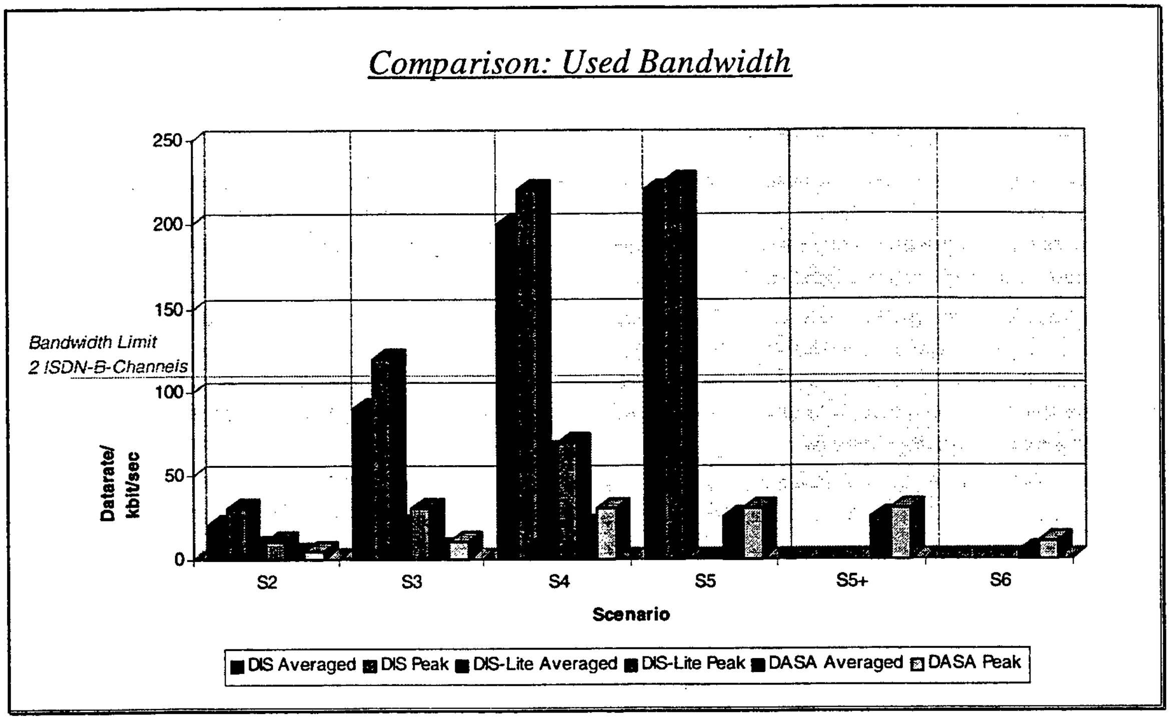


Fig. 6-85 Used Bandwidth

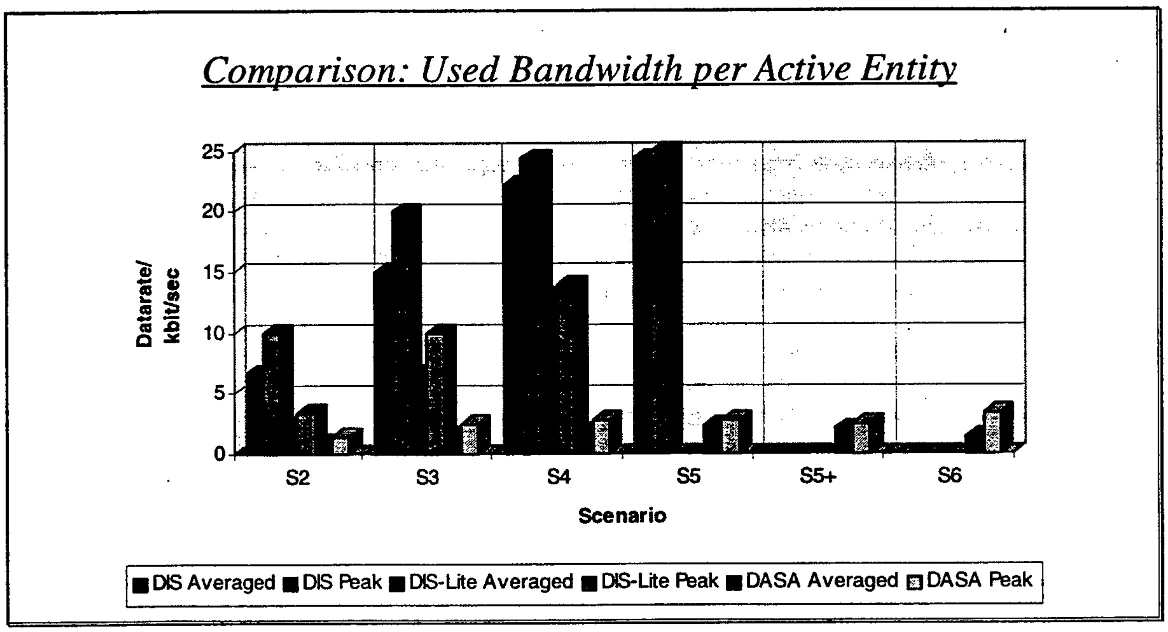


Fig. 6-86 Used Bandwidth per Entity

The initialized scenario defines the complexity by giving the training session more aircraft and therefore more possibilities to act. The complexity for the networking technology especially for the protocols are the overall number of active participants. The influences of aircraft and missiles as well as their dispersion over the network is quite different. The Fig. 6-86 compares the used protocols in their datarate produced by one active, local controlled entity (aircraft or missile) in accordance to the scenarios.
The datarate per entity produced by the protocols raises with the complexity of the scenario. While the value for the DIS-Lite protocol increases its gradient, the DIS value raise quite constantly. The DIS protocol value for S5

may be a result of the unbalanced dispersion of aircraft with the effect of reducing EMI-PDU distribution over WAN.

In contrast the Dasa protocol produces a lower datarate per active entity because of the relative small information package (SDR-PDU) for missile information exchange.

7. Abbreviations [DASA & AFRL]

3D -	Three Dimensional
2D -	Two Dimensional
A/A -	Air-to-Air
ADI	Attitude Direction Indicator
ADS -	Advanced Distributed Simulation
AFRL -	Air Force Research Laboratory
AFRL/VA	Air Force Research Laboratory Air Vehicles Directorate
AFRL/VACD	Air Force Research Laboratory Air Vehicle Simulation Branch
AMG -	Architecture Management Group
AMRAAM	Advanced Medium Range Air-to-Air Missile
AMS	and Automated Maneuvering Attack System
AOA -	Angle of Attack
AOI	Area of Interest
API -	Application Programming Interface
ASC -	Aeronautical Systems Center
BVR -	Beyond Visual Range
C4I -	Command, Control, Communications, Computers and Intelligence
CGF	Computer Generated Force
CGI	computer generated image
CGT	Computer Generated Target
CPU	Central Processing Unit
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
DARPA -	Defense Advanced Research Projects Agency
DASA	Daimler-Benz Aerospace AG
DD/PC -	Data Dictionary/Protocol Catalog
DDR&E	Director, Defense Research & Engineering
DIS -	Distributed Interactive Simulation
DMSO -	Defense Modeling and Simulation Office
DoD -	Department of Defense
DOF	Dimensions of Freedom
DSI	Defense Simulation Internet
ECM -	Electronic Counter Measures
EFOV -	Expanded Field of View
ESIG	Evans & Sutherland image generators
EVDAS -	Electronic Visual Display Attitude Sensor
FFN -	Friend, Foe, Neutral
FOV -	Field of View
FOM -	Federation Object Model
FLOT	forward line of own troops
GLOC -	G-Induced Loss of Consciousness
GPS -	Global Positioning System

GUI	-	Graphical User Interface
HDD	-	Heads Down Display
HOTAS	-	Hands On Throttle And Stick
HLA	-	High Level Architecture
HUD	-	Head-Up Display
Hz	-	Hertz
ICAAS		Integrated Control and Avionics for Air Superiority
IFF	-	Identification Friend, Foe
IEEE	-	Institute of Electrical and Electronics Engineers
IFF		Identification Friend/Foe
IG		Image Generator
I/O	-	Input/Output
IR		Infrared
IP	-	Internet Protocol
iRMX	-	Intel RMX
I/ITSEC	-	Interservice/Industry Training Systems and Education Conference
Km	-	Kilometers
LAN	-	Local Area Network
LCD	-	Liquid Crystal Display
LOS	-	Line of Sight
M&S	-	Modeling & Simulation
MCS	-	Manned Combat Station
MLE	-	Missile Launch Envelope
MOU		Memorandum of Understanding
MPD	-	Multipurpose Display
MRM	-	Medium Range Missile
NED	-	North-East-Down
NETS	-	Network Evaluation for Training and Simulation
NIC		Network Interface Computer
NIU	-	Network Interface Unit
nm or NM		Nautical Miles
NZ	-	Normal Acceleration
OMT	-	Object Model Template
OTW	-	Out The Window
PDT	-	Primary Designated Target
PDU	-	Protocol Data Unit
P_k	-	Probability of Kill
PLA	-	Power Lever Angle
PRF		Pulse Repetition Frequency
PTT		Press-To-Talk
PVI	-	Pilot Vehicle Interface
RCS	-	Radar Cross Section
RMAX1	-	Maximum Effective Missile Launch Range (3G endgame maneuver)
RMAX2	-	Maximum Effective Missile Launch Range (6G maneuver at 10 Km)

RMIN	-	Minimum Missile Launch Range
RMS	-	Reflective Memory System
RTI	-	Run Time Interface
RWR	-	Radar Warning Receiver
SA	-	Situation Awareness
SAM	-	Surface-to-air-Missile
SBIR	-	Small Business Innovative Research
SCC		Simulation Control Console
SD	-	Situation Display
SG	-	Silicon Graphics
SNAP	-	Simulation Network Analysis Project
SOM	-	Simulation Object Model
SOW		Statement of Work
SPO	-	Systems Program Office
SRM	-	Short Range Missile
STGVIP	-	Special Task Group for Vision Implementation Plan
STOW	-	Synthetic Theater of War
STOW-E		Synthetic Theater of War in Europe
STT		Single Target Track
TBD	-	To Be Determined
TRACE		Transatlantic Research into Air Combat Engagements Program
TSPG	-	Training Systems Product Group
TWS	-	Track While Scan
UAV		Unmanned Air Vehicle
UDP/IP	-	User Datagram Protocol/Internet Protocol
USAF	-	United States Air Force
USD(A&T)		Under Secretary of Defense for Acquisition and Technology
UTD	-	Unit Training Device
VBMS		Virtual Battlefield Management System
VLO		Verbundene Luftkampf Operationen (German long haul network simulation program)
VVI		Vertical Velocity Indicator
WAN	-	Wide Area Network
WASIF		Weapon System Simulation in Flight
WOW	-	Weight on Wheels
WPAFB	-	Wright- Patterson Air Force Base
WVR	-	Within Visual Range

8. References [DASA & AFRL]

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9. Appendix A - SNAP Measurements [AFRL]

Date	Network	Protocol	Implementation	Latency (DASA to WL)	Latency (WL to DASA)
30 October 1996	ISDN (64K)	DIS 2.0.4	DASA	Average: **95.7 ms** Min: 83.4 ms Max: 127.4 ms Stdev: 6.7 ms	Average: **119.6 ms** Min: 108.2 ms Max: 132.6 ms Stdev: 3.8 ms
31 October 1996	DSI (128K)	DIS 2.0.4	DASA	Average: **131.3 ms** Min: 122.6 ms Max: 169.7 ms Stdev: 3.4 ms	Average: **146.7 ms** Min: 136.8 ms Max: 184.8 ms Stdev: 4.0 ms
17 January 1997	DSI (128K)	DASA	DASA	Average: **141 ms**	no PDU
4 March 1997				*bad GPS*	*bad GPS*
6 March 1997				*bad GPS*	*bad GPS*
11 March 1997				*bad GPS*	*bad GPS*
14 March 1997	DSI (128K)	DASA	DASA	Average: **145.7 ms** Min: 142.9 ms Max: 161.3 ms Stdev: 2.3 ms	no PDU
14 March 1997	DSI (128K)	DASA	DASA	Average: **185.7 ms** Min: 145.0 ms Max: 557.2 ms Stdev: 47.7 ms	Average: **148.7 ms** Min: 143.2 ms Max: 169.8 ms Stdev: 5.5 ms
20 May 1997	ISDN (128K)	DASA	DASA	*bad data*	*bad data*
20 May 1997	ISDN (128K)	DIS	VR-Link	Average: **103.5 ms** Min: 97.6 ms Max: 151.5 ms Stdev: 6.9 ms	Average: **128.5 ms** Min: 72.4 ms Max: 233.4 ms Stdev: 29.2 ms
20 May 1997	ISDN (128K)	DIS	VR-Link	Average: **102.7 ms** Min: 97.6 ms Max: 135.5 ms Stdev: 5.5 ms	Average: **102.9 ms** Min: 97.4 ms Max: 121.3 ms Stdev: 5.5 ms
20 May 1997	ISDN (128K)	DIS	VR-Link	Average: **103.4 ms** Min: 97.6 ms Max: 143.8 ms Stdev: 6.4 ms	Average: **103.2 ms** Min: 97.4 ms Max: 136.7 ms Stdev: 6.1 ms
20 May 1997	ISDN (128K)	DIS-Lite	VR-Link	Average: **97.6 ms** Min: 30.8 ms Max: 207.5 ms Stdev: 22.6 ms	Average: **93.6 ms** Min: 86.5 ms Max: 135.5 ms Stdev: 7.6 ms

20 May 1997	ISDN (128K)	DASA	DASA	*bad data*	*bad data*
21 May 1997	ISDN (128K)	DIS	VR-Link	*bad GPS*	*bad GPS*
22 May 1997	DSI (128K)	DIS	VR-Link	*bad software*	*bad software*
22 May 1997	DSI (128K)	DIS	VR-Link	*bad software*	*bad software*
22 May 1997	DSI (128K)	DIS-Lite	VR-Link	no PDU	Average: **142.6 ms** Min: 96.1 ms Max: 179.6 ms Stdev: 10.0 ms
22 May 1997	DSI (128K)	DIS-Lite	VR-Link	no PDU	Average: **142.5 ms** Min: 89.5 ms Max: 213.8 ms Stdev: 12.2 ms
22 May 1997	DSI (128K)	DASA	DASA	Average: **161.9 ms** Min: 155.7 ms Max: 210.0 ms Stdev: 7.0 ms	Average: **143.5 ms** Min: 138.5 ms Max: 203.6 ms Stdev: 7.3 ms
22 May 1997	DSI (128K)	DASA	DASA	Average: **160.9 ms** Min: 156.0 ms Max: 243.3 ms Stdev: 10.9 ms	Average: **143.1 ms** Min: 138.3 ms Max: 195.6 ms Stdev: 6.3 ms
28 May 1997	DSI (128K)	DIS-Lite	VR-Link	no PDU	Average: **144.0 ms** Min: 137.9 ms Max: 200.0 ms Stdev: 5.7 ms
28 May 1997	DSI (128K)	DASA	DASA	Average: **128.2 ms** Min: 125.1 ms Max: 158.2 ms Stdev: 3.8 ms	Average: **141.9 ms** Min: 137.3 ms Max: 157.4 ms Stdev: 5.7 ms

Table 9-1: SNAP Measurements

10. Appendix B - Pilot Questionnaires [Dasa & AFRL]

10.1 Debriefing of the German Pilot [Dasa]

10.1.1 Test Run Debriefing Questionnaire

10.1.1.1 Simulation System

Did you feel your situational awareness was adequate? If not, what problems did you experience?

⇒ *yes*

⇒ *RWR excellent*

⇒ *radar contacts outside of 40 NM would be nice*

⇒ *Bullseye function would be useful*

Realizing this is a research facility, was the look and feel of the cockpit acceptable? If no, why not?

⇒ *yes*

⇒ *excellent cockpits*

Was the aircraft performance acceptable? If no, why not?

⇒ *Dasa A/C O.K.*

⇒ *AFRL A/C performance was too good., radar was too perfect*

⇒ *best results will be achieved*

Was the sensor system performance acceptable? If no, why not?

⇒ *yes*

⇒ *good overall*

⇒ *combat display and radar excellent*

Was the missile and/or gun system performance acceptable? If no, why not?

⇒ *AFRL performance was too good*

⇒ *missile performance good*

Was the pilot communications acceptable? If no, why not?

⇒ *yes*

⇒ *local communication was excellent, USA/BRD not used*

⇒ *intern. line not perfect but greatly improved*

⇒ *AFRL cockpits were not loud enough, console was too loud*

⇒ *local and intern. communication was much better on last day, actually real good*

Was there anything in the simulation that prevented you from performing a tactic normally performed in a real aircraft system?

⇒ *Dasa systems are pretty realistic for modern fighters*

⇒ *AFRL systems were too good and too perfect*

⇒ *the difference was too high*

⇒ *for a real tactical outcome you should have similar systems in realism on both sides and real performance data*

⇒ *because of unrealistic AFRL-A/C performance normal tactics were not possible*

⇒ *TACAN/Bullseye function is mandatory*

10.1.1.2 Network Targets

Was the sensor target tracking fidelity acceptable?

⇒ *it was really good but too good compared to real systems, especially the AFRL one*

⇒ *very good with lock on*

⇒ *contacts sometimes unstable but realistic*

Was the visual target tracking fidelity acceptable?

⇒ *the dome was O.K.*

⇒ *the VLO-Cockpit was not good enough*

⇒ *with the VLO-cockpit visual fights are very difficult due to screen limitations. Perhaps a small screen on each side of the cockpit to check left and right side of the flight path would help*

⇒ *good within 1NM, outside 1NM not really useable ➔ not acceptable for short range scenario*

⇒ *no, the resolution of the visual system is too marginal for this purpose*

10.1.1.3 General Issues

Any problems with this test scenario not mentioned above?

⇒ *no*

What additional thoughts do you have about today's configuration?

⇒ *get same performance data and use realistic data*

⇒ *for future scenarios you should simulate real performance to play i.e.F-4 vs. F-15*

⇒ *for an operational model there must be a coordinated initialization procedure and an administrator being responsible for A/C and weapon performance databases*

⇒ *however, it is depending on all participating players and their systems. There is the need of high standardization of the protocol, databases and subsystems, responsible for the administrative part*

What is your overall impression of this simulation scenario?

⇒ *With the above mentioned restrictions it should be very interesting with a good practical training outcome*

⇒ *overall very good, however due to unreal A/C-performance not all tactical aspects could be evaluated*

⇒ *national security interests will be difficult to combine*

⇒ *can data be secured in the phone net or do we need a separate one*

10.1.2 Final Debriefing Questionnaire

The work out while this questionnaire shifts to a general discussion. The results on that is summarized in the translated abstract of the official report of OLT Kleinheyer

10.1.2.1 Application Issues

1. Do you feel long-haul networking would be useful in conducting joint training simulation exercises at the engagement level?

2. Do you feel long-haul networking would be useful in evaluating new weapon system development?
3. Do you feel long-haul networking could be useful in conducting a joint mission?
4. Would long-haul networking be more useful if classified systems are used?
5. Would long-haul networking be useful for any other application?

10.1.2.2 General Issues

1. Overall, was there anything that caused significant problems for you during the test runs?
2. What is your overall impression of networked simulations?
3. Do you have any additional comments or suggestions?

10.1.3 Report of OLT Kleinheyer

The following is a translated abstract of the official report of OLT Kleinheyer to the BWB which summarizes the daily debriefing nearly completely. Statements which are not covered by this report are worked out in the last of these chapters.

10.1.3.1 The Experimental System

It was proved that a stable transatlantic connection is possible without any restrictions.

The developed training scenarios were very realistic and well suited to the evaluation of the configured system.

10.1.3.2 The Evaluation of the TRACE Program and a Connected Training Facility in general

The tactical training together with and against the US-pilots was possible with a high degree of effectiveness even with very little preparation time and briefing phase over the telephone.

After a familiarization phase, the ability of the pilots increased especially with the use of BVR-weapons. The situational awareness of the crews improved during the production runs.

Basically, the interconnection of manned simulations, when compared to a single full mission simulator, increases the tactical training possibilities.
The knowledge and the tactical behavior of an opponent has human factors and are thus even more realistic. This means that you can achieve the highest grade on tactical reality. Additionally, the coordination and communication of the own forces (2-, 3-, 4-ship) can be practiced and debriefed effectively.
This leads to high training graduation and standardization within the joining units. Because of these reasons, at least a national simulator connection should be strived for.

A interconnection of flight simulators in the role of fighters is desirable anyway. From the point of view of a fighter pilot, the following components of an air combat engagement should be added:

- GCI,
- fighter bomber,
- computer generated SAM,
- ECR,
- bomber,
- RECCE,
- the connectivity of the full mission simulator, which normally acts as a single standalone unit.

Furthermore, additonal points to conside for interconnected training are:

1. Because a force unit's normal size for tactical training is up to 4 aircraft, there should be at least 4 simulators connected within one local unit, including a possible full mission simulator.

2. There is a potential need for a powerful editing and managing tool in the form of a scenario manager for effective preparation, instruction and evaluation of training with interconnected simulations on complex scenarios. Without such a system the learning effect for trainees would be severely decreased and the full spectrum of the connected simulators could not be achieved. A windows oriented desktop would be advised.
3. Any of these scenario managers should be designed to be used standalone as well as the master of the entire simulation scenario. That means that every unit has the possibility to act on its own interests and initiatives. This could allow for a great deal of flexibility and work distribution of an interconnected Simulation.
4. The success of such a low cost simulation would depend decidedly on a compromise between the cockpit layouts of the expensive full mission simulator and a low cost solution. The decision on what functionality has to be integrated and its realization can only be done in cooperation with operational pilots. The layout of the cockpit must be selected based on the best solution for the resulting quality for the tactical training and not based solely on the acceptance of the aircraft crew.
5. A connecting technology is only reasonable if there are no restrictions on the training effects because of security concerns. That means that it must be possible to base the running simulation of the real data of all involved weapon systems. Only training with realistic weapon and aircraft performance simulations leads to tactical knowledge.
6. There has to be a solution for a low cost 360 degree out of the window view, which enables the wingman to perform formation flight.

10.1.3.3 Interconnected Simulation Training and Possible Problems for the Operational Use

1. A cluster of up to four locally networked simulators would be reasonable for units with 2-, 3- or 4-ships training against CGF's. This would be an of advantage, especially for younger crews practicing tactical maneuvers immediately after their type rating. The coordination and the means of communication would be the emphasis in such training.
2. The next step would then involve more and more military units (as other air forces, GCI, etc.). The whole mechanism of national training could then be practiced. The national standards would increase to a higher level and tactical airborne flight preparation without any examples from the pastcould be realized. A tactical simulator interconnection essentially contributes to the ability of future crews.
3. At least the interconnection between NATO-nations is a logical conclusion and follow-on of the work done. There is then a need for a MOU concerning the handling of basic data. Standardized regulations of all participants has to be achieved.

10.2 Debriefing of the US Pilot [AFRL]

10.2.1 Test Run Debriefing Questionnaire

10.2.1.1 Simulation System

Did you feel your situational awareness was adequate? If not, what problems did you experience?

⇒ *Most answers yes.*

⇒ *Virtual EFOV helpful*

⇒ *Improve by showing target aspect in HUD (when locked)*

⇒ *Couldn't see other aircraft when outside forward screen FOV.*

⇒ *Need aspect carat and AMRAAM R1/R2/Rmax.*

⇒ *Virtual wingman/bogey in HUD doesn't agree with HDD (unknown vs F-22)*

⇒ *Need threat missile status. Range info on threat missile.*

⇒ *MCS inadequate in within visual range.*

Realizing this is a research facility, was the look and feel of the cockpit acceptable? If no, why not?

⇒ *All answers yes.*

⇒ *Need RWR display with range and azimuth info on threat missiles.*

⇒ *Excellent coordination between German/American 2-ships (scenario 5.2)*

Was the aircraft performance acceptable? If no, why not?

⇒ *Optimistic. Accelerating at M1.2 in steep climb.*

⇒ *Mil power climb and acceleration were weak.*

⇒ *Great top end accelerations*

⇒ *Too good, Accelerating supersonic at 30 deg. nose up*

Was the sensor system performance acceptable? If no, why not?

⇒ *Yes*

⇒ *Too good*

⇒ *Not realistic -- too simple.*

Was the missile and/or gun system performance acceptable? If no, why not?

⇒ *Missile launch zones (maximum engagement distance = R1) appeared too short. Launched missile and had it reach target outside of the max launch cue.*

⇒ *Missile max kinematic capability was not realistically displayed on HUD or HDD*

⇒ *Gun lagged pipper*

Was the pilot communications acceptable? If no, why not?

⇒ *Volume too low.*

⇒ *OK*

⇒ *Could hear opponents control room*

Was there anything in the simulation that prevented you from performing a tactic normally performed in a real aircraft system?

⇒ *Most answers no.*

⇒ *No wrap around video/limited FOV*

⇒ *Could do more tactically that in an F-15*

⇒ *MLE bad... No Rmax1, Rmax2. Envelope jitters.*

⇒ *Lofted steering for MRM missiles was not modeled.*

⇒ *Chaff in scenario 4B.*

⇒ *No bullseye data.*

⇒ *RWR info*

10.2.1.2 Network Targets

Was the sensor target tracking fidelity acceptable?

⇒ *all answers yes*

⇒ *One pilot felt it was too good to be true.*

Was the visual target tracking fidelity acceptable?

⇒ *most answers yes*

⇒ *Minor location changes (jumps) were noticeable.*

⇒ *Fuzzy video in dome but acceptable.*

10.2.1.3 General Issues

Any problems with this test scenario not mentioned above?

⇒ *Most answers no*

⇒ *His missile (launched outside 30 nm) was able to chase this aircraft down in the beam. This is a very "high performance" missile.*

What additional thoughts do you have about today's configuration?

⇒ *Good*

⇒ *Make R1, R2 cues more accurate*

What is your overall impression of this simulation scenario?

⇒ *Good*

⇒ *Fine for BVR*

10.2.2 Final Debriefing Questionnaire

10.2.2.1 Application Issues

Do you feel long-haul networking would be useful in conducting joint training simulation exercises at the engagement level?

⇒ *All yes*

⇒ *BVR with realistic models for aero, sensors, weapons, and terrain.*

⇒ *Absolutely. Impressive*

⇒ *Security issues require a lot of work but if overcome the whole act should be real useful.*

Do you feel long-haul networking would be useful in evaluating new weapon system development?

⇒ *All yes*

⇒ *If you have realistic missiles.*

⇒ *Classification level might make this difficult.*

⇒ *Avionics and other PVI is form fit for this type testing/eval.*

⇒ *In the sense of larger scale man-in-the-loop sim. and eval. It would be useful. New weapons need to be evaluated at the mission and campaign level.*

Do you feel long-haul networking could be useful in conducting a joint mission?

⇒ Yes

⇒ with realistic models

Would long-haul networking be more useful if classified systems are used?

⇒ *Yes*

⇒ *realistic models*

⇒ *Classified systems will be absolute requirements. Utility will be extremely limited at the unclass level.*

Would long-haul networking be useful for any other application?

⇒ *Mission rehearsal*

⇒ *Battlefield management, intel*

⇒ *International/NATO air refueling procedures practice.*

⇒ *Training. Tactics development. Concept exploration. Help reduce costs.*

10.2.2.2 General Issues

Overall, was there anything that caused significant problems for you during the test runs?

⇒ *Better coordination ahead of time to minimize waiting time and comm load*

⇒ *During large engagements (6 vs many, etc) no RWR/spikes transmitted (bandwidth limitation)*

⇒ *Limited bandwidth.*

What is your overall impression of networked simulations?

⇒ *Networking is fine if the simulations at the ends work.*

⇒ *Excellent possibilities for training*

⇒ *Excellent -- great improvement over previous attempts.*

⇒ *Very nice.*

Do you have any additional comments or suggestions?

⇒ *System testing or training procedures should be planned to more detail prior to going real-time.*

11. Appendix C - Scenario Simulation Data [DASA]

11.1 Scenario 1

*************** START SCENARIO **

ScenarioName /usr/people/SM/SCENARIOS/TRACE/S1.dir/S1.scn

****

NoUnits 2

---------------------- FLOT with 2 points -----------------

0 Lat 36.997612 Lon -114.370201

1 Lat 35.054893 Lon -114.511803

ENTITY Role Description

No Meaning
0 NEUTRAL_ROLE
1 BOMBER
2 FIGHTER
3 DETACHED ESCORT
4 CLOSE ESCORT
5 RECCE
6 STANDOFFJAMMER
7 AWACS

ENTITY Force Description

No Meaning
0 NEUTRAL
1 BLUE
2 RED

ENTITY Kind Description

No Meaning
0 OTHER
1 PLATFORM
2 MUNITION

ENTITY Domain Description

No Meaning
0 OTHER
1 LAND
2 AIR
3 SURFACE

Path /usr/people/SM/SCENARIOS/TRACE/S1.dir EntityName CAP_WL

MANNED Entity: SiteId 12 AppId 1 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.329945 Lon -115.569717 Alt/meter 2209.759644 Heading 90.000 speed/knots 0.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S1.dir EntityName CAP_DASA

MANNED Entity: SiteId 11 AppId 0 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.329693 Lon -115.569092 Alt/meter 2209.759644 Heading 90.000 speed/knots 0.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

***************** END SCENARIO **

11.2 Scenario 2

*************** START SCENARIO **

ScenarioName /usr/people/SM/SCENARIOS/TRACE/S2.dir/S2.scn

****

NoUnits 2

---------------------- FLOT with 2 points ----------------

0 Lat 36.997612 Lon -114.370201

1 Lat 35.054893 Lon -114.511803

ENTITY Role Description

No Meaning

0 NEUTRAL_ROLE

1 BOMBER

2 FIGHTER

3 DETACHED ESCORT

4 CLOSE ESCORT

5 RECCE

6 STANDOFFJAMMER

7 AWACS

ENTITY Force Description

No Meaning

0 NEUTRAL

1 BLUE

2 RED

ENTITY Kind Description

No Meaning

0 OTHER

1 PLATFORM

2 MUNITION

ENTITY Domain Description

No Meaning

0 OTHER

1 LAND

2 AIR

3 SURFACE

Path /usr/people/SM/SCENARIOS/TRACE/S2.dir EntityName CAP_WL

MANNED Entity: SiteId 12 AppId 1 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.329945 Lon -115.569717 Alt/meter 2209.759644 Heading 90.000 speed/knots 0.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S2.dir EntityName CAP_DASA

MANNED Entity: SiteId 11 AppId 0 EntId 0 FrcId 2 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.431980 Lon -114.275795 Alt/meter 4632.875391 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

***************** END SCENARIO **

11.3 Scenario 3A

*************** START SCENARIO **

ScenarioName /usr/people/SM/SCENARIOS/TRACE/S3A.dir/S3A.scn

****

NoUnits 4

---------------------- FLOT with 2 points ----------------

0 Lat 36.997612 Lon -114.370201

1 Lat 35.054893 Lon -114.511803

ENTITY Role Description

No Meaning

0 NEUTRAL_ROLE

1 BOMBER

2 FIGHTER

3 DETACHED ESCORT

4 CLOSE ESCORT

5 RECCE

6 STANDOFFJAMMER

7 AWACS

ENTITY Force Description

No Meaning

0 NEUTRAL

1 BLUE

2 RED

ENTITY Kind Description

No Meaning

0 OTHER

1 PLATFORM

2 MUNITION

ENTITY Domain Description

No Meaning

0 OTHER

1 LAND

2 AIR

3 SURFACE

Path /usr/people/SM/SCENARIOS/TRACE/S3A.dir EntityName CAP_WL1

MANNED Entity: SiteId 12 AppId 1 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.329693 Lon -115.569092 Alt/meter 2209.759644 Heading 90.000 speed/knots 0.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S3A.dir EntityName CAP_DASA1

MANNED Entity: SiteId 11 AppId 0 EntId 0 FrcId 2 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.609104 Lon -114.136975 Alt/meter 4571.916504 Heading 290.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 2

GUN: Rounds 150

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S3A.dir EntityName CAP_WL2

MANNED Entity: SiteId 12 AppId 1 EntId 1 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.329945 Lon -115.569717 Alt/meter 2209.759644 Heading 90.000 speed/knots 0.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S3A.dir EntityName CAP_DASA2

MANNED Entity: SiteId 11 AppId 3 EntId 0 FrcId 2 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.598141 Lon -114.140966 Alt/meter 4571.916504 Heading 290.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 2

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

***************** END SCENARIO ***

11.4 Scenario 3B

*************** START SCENARIO **

ScenarioName /usr/people/SM/SCENARIOS/TRACE/S3B.dir/S3B.scn

****

NoUnits 4

---------------------- FLOT with 2 points ----------------

0 Lat 36.997612 Lon -114.370201

1 Lat 35.054893 Lon -114.511803

ENTITY Role Description

No Meaning

0 NEUTRAL_ROLE

1 BOMBER

2 FIGHTER

3 DETACHED ESCORT

4 CLOSE ESCORT

5 RECCE

6 STANDOFFJAMMER

7 AWACS

ENTITY Force Description

No Meaning

0 NEUTRAL

1 BLUE

2 RED

ENTITY Kind Description

No Meaning

0 OTHER

1 PLATFORM

2 MUNITION

ENTITY Domain Description

No Meaning

0 OTHER

1 LAND

2 AIR

3 SURFACE

Path /usr/people/SM/SCENARIOS/TRACE/S3B.dir EntityName CAP_WL1

MANNED Entity: SiteId 12 AppId 1 EntId 0 FrcId 2 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.609104 Lon -114.136975 Alt/meter 4571.916504 Heading 290.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 2

GUN: Rounds 150

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S3B.dir EntityName CAP_DASA1

MANNED Entity: SiteId 11 AppId 0 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.329693 Lon -115.569092 Alt/meter 2209.759644 Heading 90.000 speed/knots 0.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S3B.dir EntityName CAP_WL2

MANNED Entity: SiteId 12 AppId 1 EntId 1 FrcId 2 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.598141 Lon -114.140966 Alt/meter 4571.916504 Heading 290.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 2

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path /usr/people/SM/SCENARIOS/TRACE/S3B.dir EntityName CAP_DASA2

MANNED Entity: SiteId 11 AppId 3 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.329945 Lon -115.569717 Alt/meter 2209.759644 Heading 90.000 speed/knots 0.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

**************** END SCENARIO **

11.5 Scenario 4A

*************** START SCENARIO **

ScenarioName S4A.dir/S4A.scn

****

NoUnits 8

---------------------- FLOT with 2 points ----------------

0 Lat 36.988068 Lon -114.376099

1 Lat 35.064438 Lon -114.505898

ENTITY Role Description

No Meaning
0 NEUTRAL_ROLE
1 BOMBER
2 FIGHTER
3 DETACHED ESCORT
4 CLOSE ESCORT
5 RECCE
6 STANDOFFJAMMER
7 AWACS

ENTITY Force Description

No Meaning
0 NEUTRAL
1 BLUE
2 RED

ENTITY Kind Description

No Meaning
0 OTHER
1 PLATFORM
2 MUNITION

ENTITY Domain Description

No Meaning
0 OTHER
1 LAND
2 AIR
3 SURFACE

Path S4A.dir EntityName BOMBER_CGT4

UNMANNED Entity: SiteId 11 AppId 4 EntId 0 FrcId 2 RoleId 1

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 35.999920 Lon -114.098793 Alt/meter 1066.780518 Heading 310.000 speed/knots 480.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

FREEFALL_BOMB: Qty 8

---------------------- EW --------------------------------

FLARE: Qty 30

---------------------- WAYPOINT ROUTE --------------------

WPTROUTE nziel 6 nwpt 7

WPOINT 0 Active 1 Lat 36.003582 Lon -114.129776

WPOINT 1 Active 1 Lat 36.195702 Lon -114.376099

WPOINT 2 Active 1 Lat 36.081146 Lon -114.830406

WPOINT 3 Active 1 Lat 36.193317 Lon -115.063461

WPOINT 4 Active 1 Lat 36.133652 Lon -115.452866

WPOINT 5 Active 1 Lat 36.331741 Lon -115.547272

WPOINT 6 Active 1 Lat 36.233891 Lon -114.296448

Path S4A.dir EntityName CAP_WL2

MANNED Entity: SiteId 12 AppId 1 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.248249 Lon -115.498596 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path S4A.dir EntityName CAP_CGT1

UNMANNED Entity: SiteId 11 AppId 4 EntId 1 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.233891 Lon -115.498291 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path S4A.dir EntityName ESCORT_DASA2

MANNED Entity: SiteId 11 AppId 3 EntId 0 FrcId 2 RoleId 3

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.344395 Lon -114.098793 Alt/meter 1828.766602 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4A.dir EntityName CAP_WL1

MANNED Entity: SiteId 12 AppId 1 EntId 1 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.264915 Lon -115.498596 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4A.dir EntityName CAP_CGT2

UNMANNED Entity: SiteId 11 AppId 4 EntId 2 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.279236 Lon -115.498001 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4A.dir EntityName BOMBER_CGT3

UNMANNED Entity: SiteId 2 AppId 2 EntId 0 FrcId 2 RoleId 1

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.016587 Lon -114.098793 Alt/meter 1066.780518 Heading 310.000 speed/knots 480.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

FREEFALL_BOMB: Qty 8

----------------------- EW ---------------------------------

FLARE: Qty 30

----------------------- WAYPOINT ROUTE ---------------------

WPTROUTE nziel 6 nwpt 7

WPOINT 0 Active 1 Lat 36.020287 Lon -114.126823

WPOINT 1 Active 1 Lat 36.202862 Lon -114.373154

WPOINT 2 Active 1 Lat 36.090691 Lon -114.821556

WPOINT 3 Active 1 Lat 36.193317 Lon -115.063461

WPOINT 4 Active 1 Lat 36.133652 Lon -115.452866

WPOINT 5 Active 1 Lat 36.331741 Lon -115.547272

WPOINT 6 Active 1 Lat 36.233891 Lon -114.296448

Path S4A.dir EntityName ESCORT_DASA1

MANNED Entity: SiteId 11 AppId 0 EntId 0 FrcId 2 RoleId 3

----------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.333254 Lon -114.098793 Alt/meter 1828.766602 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

----------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

----------------------- EW ---------------------------------

FLARE: Qty 30

***************** END SCENARIO **

11.6 Scenario 4B

*************** START SCENARIO **

ScenarioName S4B.dir/S4B.scn

****

NoUnits 8

----------------------- FLOT with 2 points ----------------

0 Lat 36.988068 Lon -114.376099

1 Lat 35.064438 Lon -114.505898

ENTITY Role Description

No Meaning

0 NEUTRAL_ROLE

1 BOMBER

2 FIGHTER

3 DETACHED ESCORT

4 CLOSE ESCORT

5 RECCE

6 STANDOFFJAMMER

7 AWACS

ENTITY Force Description

No Meaning

0 NEUTRAL

1 BLUE

2 RED

ENTITY Kind Description

No Meaning

0 OTHER

1 PLATFORM

2 MUNITION

ENTITY Domain Description

No Meaning

0 OTHER

1 LAND

2 AIR

3 SURFACE

Path S4B.dir EntityName BOMBER_CGT4

UNMANNED Entity: SiteId 11 AppId 4 EntId 0 FrcId 2 RoleId 1

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 35.999920 Lon -114.098793 Alt/meter 1066.780518 Heading 310.000 speed/knots 480.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

FREEFALL_BOMB: Qty 8

---------------------- EW --------------------------------

FLARE: Qty 30

---------------------- WAYPOINT ROUTE --------------------

WPTROUTE nziel 6 nwpt 7

WPOINT 0 Active 1 Lat 36.003582 Lon -114.129776

WPOINT 1 Active 1 Lat 36.195702 Lon -114.376099

WPOINT 2 Active 1 Lat 36.081146 Lon -114.830406

WPOINT 3 Active 1 Lat 36.193317 Lon -115.063461

WPOINT 4 Active 1 Lat 36.133652 Lon -115.452866

WPOINT 5 Active 1 Lat 36.331741 Lon -115.547272

WPOINT 6 Active 1 Lat 36.233891 Lon -114.296448

Path S4B.dir EntityName CAP_CGT1

UNMANNED Entity: SiteId 11 AppId 4 EntId 1 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.233891 Lon -115.498291 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4B.dir EntityName CAP_DASA1

MANNED Entity: SiteId 11 AppId 0 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.264915 Lon -115.498596 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4B.dir EntityName CAP_DASA2

MANNED Entity: SiteId 11 AppId 3 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.248249 Lon -115.498596 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4B.dir EntityName CAP_CGT2

UNMANNED Entity: SiteId 11 AppId 4 EntId 2 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.279236 Lon -115.498001 Alt/meter 3657.533203 Heading 90.000 speed/knots 500.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4B.dir EntityName BOMBER_CGT3

UNMANNED Entity: SiteId 2 AppId 2 EntId 0 FrcId 2 RoleId 1

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.016587 Lon -114.098793 Alt/meter 1066.780518 Heading 310.000 speed/knots 480.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

FREEFALL_BOMB: Qty 8

---------------------- EW -------------------------------

FLARE: Qty 30

---------------------- WAYPOINT ROUTE --------------------

WPTROUTE nziel 6 nwpt 7

WPOINT 0 Active 1 Lat 36.020287 Lon -114.126823

WPOINT 1 Active 1 Lat 36.202862 Lon -114.373154

WPOINT 2 Active 1 Lat 36.090691 Lon -114.821556

WPOINT 3 Active 1 Lat 36.193317 Lon -115.063461

WPOINT 4 Active 1 Lat 36.133652 Lon -115.452866

WPOINT 5 Active 1 Lat 36.331741 Lon -115.547272

WPOINT 6 Active 1 Lat 36.233891 Lon -114.296448

Path S4B.dir EntityName ESCORT_WL2

MANNED Entity: SiteId 12 AppId 1 EntId 0 FrcId 2 RoleId 3

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.344395 Lon -114.098793 Alt/meter 1828.766602 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ---------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW -------------------------------

FLARE: Qty 30

Path S4B.dir EntityName ESCORT_WL1

MANNED Entity: SiteId 12 AppId 1 EntId 1 FrcId 2 RoleId 3

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.333254 Lon -114.098793 Alt/meter 1828.766602 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

***************** END SCENARIO **

11.7 Scenario 5

************** START SCENARIO ***

ScenarioName S5.dir/S5.scn

****

NoUnits 8

---------------------- FLOT with 2 points ----------------

0 Lat 36.988068 Lon -114.376099

1 Lat 35.064438 Lon -114.505898

ENTITY Role Description

No	Meaning
0	NEUTRAL_ROLE
1	BOMBER
2	FIGHTER
3	DETACHED ESCORT
4	CLOSE ESCORT
5	RECCE
6	STANDOFFJAMMER
7	AWACS

ENTITY Force Description

No	Meaning
0	NEUTRAL
1	BLUE
2	RED

ENTITY Kind Description

No	Meaning
0	OTHER
1	PLATFORM
2	MUNITION

ENTITY Domain Description

No	Meaning
0	OTHER
1	LAND
2	AIR
3	SURFACE

Path S5.dir EntityName CAP_DASA1

MANNED Entity: SiteId 11 AppId 0 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.289021 Lon -115.724564 Alt/meter 4571.916504 Heading 90.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path S5.dir EntityName CAP_DASA2

MANNED Entity: SiteId 11 AppId 3 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.248211 Lon -115.724266 Alt/meter 4571.916504 Heading 90.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW --------------------------------

FLARE: Qty 30

Path S5.dir EntityName CAP_WL1

UNMANNED Entity: SiteId 1 AppId 1 EntId 0 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.307400 Lon -115.723679 Alt/meter 4571.916504 Heading 90.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 150

---------------------- EW --------------------------------

FLARE: Qty 30

Path S5.dir EntityName RFB02

UNMANNED Entity: SiteId 11 AppId 4 EntId 0 FrcId 2 RoleId 1

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 35.999920 Lon -114.098793 Alt/meter 1066.780518 Heading 310.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

FREEFALL_BOMB: Qty 8

---------------------- EW --------------------------------

FLARE: Qty 30

---------------------- WAYPOINT ROUTE --------------------

WPTROUTE nziel 6 nwpt 7

WPOINT 0 Active 1 Lat 36.003582 Lon -114.129776

WPOINT 1 Active 1 Lat 36.112171 Lon -114.387901

WPOINT 2 Active 1 Lat 36.081146 Lon -114.830406

WPOINT 3 Active 1 Lat 36.193317 Lon -115.063461

WPOINT 4 Active 1 Lat 36.133652 Lon -115.452866

WPOINT 5 Active 1 Lat 36.331741 Lon -115.547272

WPOINT 6 Active 1 Lat 36.233891 Lon -114.296448

Path S5.dir EntityName RF03

UNMANNED Entity: SiteId 2 AppId 2 EntId 0 FrcId 2 RoleId 3

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.372314 Lon -114.101746 Alt/meter 3047.944336 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 2

---------------------- EW --------------------------------

FLARE: Qty 30

---------------------- WAYPOINT ROUTE --------------------

WPTROUTE nziel 4 nwpt 5

WPOINT 0 Active 1 Lat 36.372314 Lon -114.131241

WPOINT 1 Active 1 Lat 36.252983 Lon -114.346596

WPOINT 2 Active 1 Lat 36.463009 Lon -114.924805

WPOINT 3 Active 1 Lat 36.338902 Lon -115.514816

WPOINT 4 Active 1 Lat 36.114559 Lon -114.328896

Path S5.dir EntityName RF01

UNMANNED Entity: SiteId 2 AppId 2 EntId 1 FrcId 2 RoleId 3

---------------------- POSITION/ATTITUDE SPEED ------------

Lat 36.349920 Lon -114.098793 Alt/meter 3047.944336 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 2

---------------------- EW ---------------------------------

FLARE: Qty 30

---------------------- WAYPOINT ROUTE --------------------

WPTROUTE nziel 4 nwpt 5

WPOINT 0 Active 1 Lat 36.349640 Lon -114.117973

WPOINT 1 Active 1 Lat 36.252983 Lon -114.346596

WPOINT 2 Active 1 Lat 36.463009 Lon -114.924805

WPOINT 3 Active 1 Lat 36.338902 Lon -115.514816

WPOINT 4 Active 1 Lat 36.114559 Lon -114.328896

Path S5.dir EntityName RF02

UNMANNED Entity: SiteId 2 AppId 2 EntId 2 FrcId 2 RoleId 3

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.333254 Lon -114.098793 Alt/meter 3047.944336 Heading 270.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 2

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 2

---------------------- EW ---------------------------------

FLARE: Qty 30

---------------------- WAYPOINT ROUTE --------------------

WPTROUTE nziel 4 nwpt 5

WPOINT 0 Active 1 Lat 36.331741 Lon -114.117973

WPOINT 1 Active 1 Lat 36.251789 Lon -114.345123

WPOINT 2 Active 1 Lat 36.458233 Lon -114.926285

WPOINT 3 Active 1 Lat 36.338902 Lon -115.514816

WPOINT 4 Active 1 Lat 36.114559 Lon -114.328896

Path S5.dir EntityName CAP_WL2

MANNED Entity: SiteId 12 AppId 1 EntId 1 FrcId 1 RoleId 2

---------------------- POSITION/ATTITUDE SPEED -------------

Lat 36.267780 Lon -115.723969 Alt/meter 4571.916504 Heading 90.000 speed/knots 420.000 Fuel 3600.000000

EntityType: Kind 1 Domain 2 Country 0 Cat 0 SubCat 0 Specific 1

---------------------- WEAPONS ----------------------------

SR_MISSILE: Qty 4

MR_MISSILE: Qty 4

GUN: Rounds 300

---------------------- EW ---------------------------------

FLARE: Qty 30

***************** END SCENARIO ***

12. Appendix D - Selected Data Recorded During Production Runs [DASA]

Data recorded during production runs are presented as trajectory plots of aircraft and missiles.
These data have been recorded by a program on the simulation computer of the DASA dome cockpit.

Six simulation runs have been evaluated

- 3 runs of scenario S3 (2 vs 2 manned cockpits)
- 3 runs of scenario S5 („Joint Mission"; 4 manned cockpits - 2 Air Force Research Laboratory and 2 Dasa cockpits - vs 4 DASA Computer Generated Targets (CGT).

12.1 Description of Data Presentation

The data was taken every second and recorded on a disk file.
The data presentation consists of a

- trajectory plot of aircraft and missiles in the Z-Y-plane (altitude vs Y-axis)
  (solid lines : aircraft ; dashed lines : missiles)
- trajectory plot of aircraft and missiles in the X-Y-plane (trajectories projected into the horizontal plane); a summary table of symbols used is shown in Fig. 12-1. Numbers at symbols denote simulation time divided by 10.
- summary table containing information of participating aircraft starting with side, role, cockpit or CGT, time of engagement, position, Mach number and heading at start of plot. This is followed by information about fired missiles. The first row of missile information present the results of Medium Range Missiles (MRM), the second of Short Range Missiles (SRM).
  These information contains:
  - target of missile (e.g. B2 = Blue 2)
  - on the upper right side firing time of missile is shown, and end time of missile flight is shown below
  - last row of numbers show miss distance :
    true range to target at end of flight for all except DASA dome cockpit; for DASA dome cockpit, as data are available, either true range to target if seeker head had „lock on" or apparent range to target if seeker head could not lock on to target.
    miss (-2) or hit (-3) flag indicating cause of termination in case of miss

The normal flag in case of a missile hit is 0. Negative status flags can also be possible, as missile calculation will be continued if range to target is less than 300 m and a negative status flag is set. If the miss distance is then found to be within lethal radius, this also results in a legal missile hit.

List of terminating conditions :

Medium Range Missile

0 = normal flight
1 = time of flight less than minimum time for warhead activation
2 = time of flight greater than maximum time of flight (tmax = 80 sec)
3 = Mach number less than min Mach number
4 = Mach number greater than max Mach number
5 = closure speed less than min closure speed
6 = maximum acceleration dropped below „bmaxgr" at range less than rbmax
7 = seeker head had „lock on", yet range increased to 1.4 of lock range
8 = seeker head can not establish „lock on"

9 = Line of Sight (LOS) to target lost (due to terrain) after „lock on"
13 = missile hit ground
-1 = look angle exceeded
-2 = LOS rate exceeded after „lock on"
-4 = target disappeared

Short Range Missile

0 = normal flight
1 = time of flight less than minimum time for warhead activation
2 = time of flight greater than maximum time of flight (tmax = 50 sec)
3 = dynamic pressure q less than qmin after boost phase
4 = dynamic pressure q greater than qmax
5 = closure speed less than 0. after boost phase
-1 = look angle exceeded
-2 = LOS rate exceeded
-3 = Infra Red (IR) seeker lost „lock on"
(reasons can be :
- IR emissions of target decreased
- target disappeared
- missile diverted by flares)

Symbol	
●	**DASA Dome Cockpit**
✱	**Neutral DASA Dome Cockpit**
⊙	**DASA VLO Cockpit / Wright Lab Cockpit ("own force")**
⊖	**CGT ("own force")**
◘	**DASA VLO Cockpit / Wright Lab Cockpit ("foe")**
⨯	**Neutral DASA VLO Cockpit**
□	**Red CGT (free fighter or detached escort)**
△	**Red CGT (close escort)**
▣	**Red CGT (fighter bomber)**
×	**Neutral CGT**
◇	**Medium Range Missile**
⊥	**Short Range Missile**
⌘	**Chaff Drop**
✱	**Flare Drop**
✹	**Missile Kill**

Fig. 12-1 Plot Legend

12.2 Evaluation of Scenario S3 Runs

In this scenario the „blue forces" perform a „scramble takeoff" from Williams Airforce Base. The „red forces" start at a point located about 72 nm east (077) in an altitude of 15000 ft, Ma = 0.67 and a heading of 290 degrees.

Each aircraft carries 4 MRM, 4 SRM and 30 flares.

- Air Force Research Laborator cockpits are "blue side"

(run 2 on Mon Oct 27 14:25:27 1997, Fig. 12-2 to Fig. 12-4and a „blow up" plot in Fig. 12-5 and Fig. 12-6, Fig. 12-7 and Fig. 12-8)

Both blue aircraft turn to heading 270 after take off. They make advantage of their superior aircraft performance and radar sensor capability. They turn back to heading 090 after having reached about 50000 ft and Ma = 1.72, resp. 43000 ft and Ma = 2.16.

Blue 2 fires his first MRM on Red 2 at t = 177 sec (Ma = 2.35, h = 40 kft, r = 100 km - that means he has „lock on" at that range). He fires his second MRM on Red 1 at t = 199 sec (Ma = 2.50, h = 40 kft, range = 97 km).

Red 1 achieves radar „lock on" at t = 230 sec (ca. 70 km = 38 nm, maximum „lock on" range of DASA radar in TWS and MPRF-PK is somewhat less than 40 nm).

Red 1 fires his MRM at t = 236 sec (Ma = 1.34, h = 51 kft, r = 65 km).
At that moment, the MRM of Blue 2 has a range of 37 km and a closure rate of 1550 m/sec to Red 1.
At t = 255 sec, Red 1 gets a missile warning (MRM at Ma = 3.50 and closure rate still 1120 m/sec). Red 1's missile avoidance maneuver can not outrun the missile anymore (hit at t = 267 sec, see figure 7 and 8). At that time Red 1's missile range to Blue 2 is about 36 km (Ma = 3.7 and vcl = 1190 m/sec), therefore requiring at least another 25 sec for guidance update which was no more possible.

While Red 1 was attacking high, Red 2 was descending to very low altitude, trying to hide in the terrain (with radar off - no electronic emissions ! - and maintaining a mean terrain clearance of less than 600 ft). Around t = 220 sec he was also flying a „beam maneuver" against the attacking two blue aircraft, trying to use the well known „Doppler notch" phenomenon, characteristically for Pulse Doppler radars to deny radar lock. However, the radar lock of blue aircraft could obviously not be broken. Finally, after popping up at around t = 280 sec, a mutual kill occurred between Blue 2 and Red 2.

Summary of outcome :

Blue 1 :	no target hits
	survives engagement
Blue 2 :	hits Red 1 at t = 267 sec
	hits Red 2 at t = 313 sec
	hit by Red 2 at t = 317 sec
	and at t = 319 sec
	and at t = 324 sec
Red 1 :	no target hits
	hit by Blue 2 at t = 267 sec
Red 2 :	hits Blue 2 at t = 317 sec
	and at t = 319 sec
	and at t = 324 sec
	hit by Blue 2 at t = 313 sec

- DASA cockpits are „blue side"

(run 3 on Mon Oct 27 14:25:27 1997, Fig. 12-9 to Fig. 12-11and a „blow up" plot in Fig. 12-12 and Fig. 12-13)

Blue aircraft split at about t = 100 sec (Blue 1 continuing westerly heading, Blue 2 turning towards red aircraft). Red 2 disengages from fight at about t = 220 sec, after having fired two MRM's.

Red 1 engages blue aircraft giving another example of his powerful performance, starting a climb (t = 240 sec) at

h = 9400 m with Ma = 2.20 and climbing up to 16400 m within 20 sec (mean climb speed of 350 m/sec, which is about 70000 ft/min, at Ma = 2.05; more than Ma = 1.0 climb speed !; mean climb angle of 40 degrees).

Red 1 fires his first missile at t = 210 sec (which never reaches autonomous status) and his second missile at t = 267 sec in h = 18700 m at Ma = 1.60 and a climb angle of about 30 degrees. This MRM hits Blue 1 at t = 329 sec.

Red 1 continues his climb up to 20200 m, ending up with Ma 0 0.85, a very „bad" situation to outrun a MRM. Blue 2's first MRM (fired at t = 290 sec) hits Red 1 at t = 322 sec. About 10 sec later Blue 1's MRM (fired at t = 277 sec) hits Red 1. A SRM fired by Red 1 at t = 316 sec can be defeated by Blue 2 through his use of flares.

Red 1, unaffected by two missile hits, disengages from the fight. After having been hit again by the second MRM of Blue 2, he obviously accepts the kill and falls down. The third missile of Blue 2 is terminated because it loses target lock, as Red 1 is plunging into terrain.

Summary of outcome :

Blue 1 :	hits Red 1 at t = 332 sec hit by Red 1 at t = 329 sec
Blue 2 :	hits Red 1 at t = 322 sec and at t = 428 sec survives engagement
Red 1 :	hits Blue 1 at t = 329 sec hit by Blue 2 at t = 322 sec and at t = 428 sec
Red 2 :	no target hits survives engagement

- DASA cockpits are „blue side"

(run 1 on Mon Oct 27 14:56:13 1997, Fig. 12-14 to Fig. 12-16 and a „blow up" plot in Fig. 12-17 and Fig. 12-18; extract from t = 240 to 321 sec in Fig. 12-19 and Fig. 12-20)

The early firings of Red 1 and Red 2 (two firings each) result in clear misses, since both blue aircraft turned away (at t = 120 sec), yet without having fired own missiles.

Also the next two MRM's fired by Red 1 (at t = 153 sec and t = 160 sec) miss their targets. Red 1 has no more MRM's and presses on into short range engagement.

Meanwhile, Red 2 made advantage of his aircraft performance and reached Ma = 2.51 in h = 12600 m.

What comes now is an example of the superior radar sensor system. Red 2 accomplishes to fire his remaining two MRM's on to Blue 1 and Blue 2 within 3 seconds (t = 248 sec and t = 251 sec, see figures 19 and 20). Although, the blue aircraft are about 75 degrees apart, Red 2 manages to have „lock on" on both targets (or at least is able to switch locks that fast), designate and fire on to both aircraft within 3 seconds.

Both blue aircraft had engaged the „eternal life" switch and therefore continue the engagement, Blue 2 defeats Red 1's SRM by deploying flares and hits Red 2 with a MRM at t = 351 sec. Blue 1 hits Red 2 with 3 MRM's at t = 348, 349 and 352 sec.

No outcome summary → „life switch" pressed.

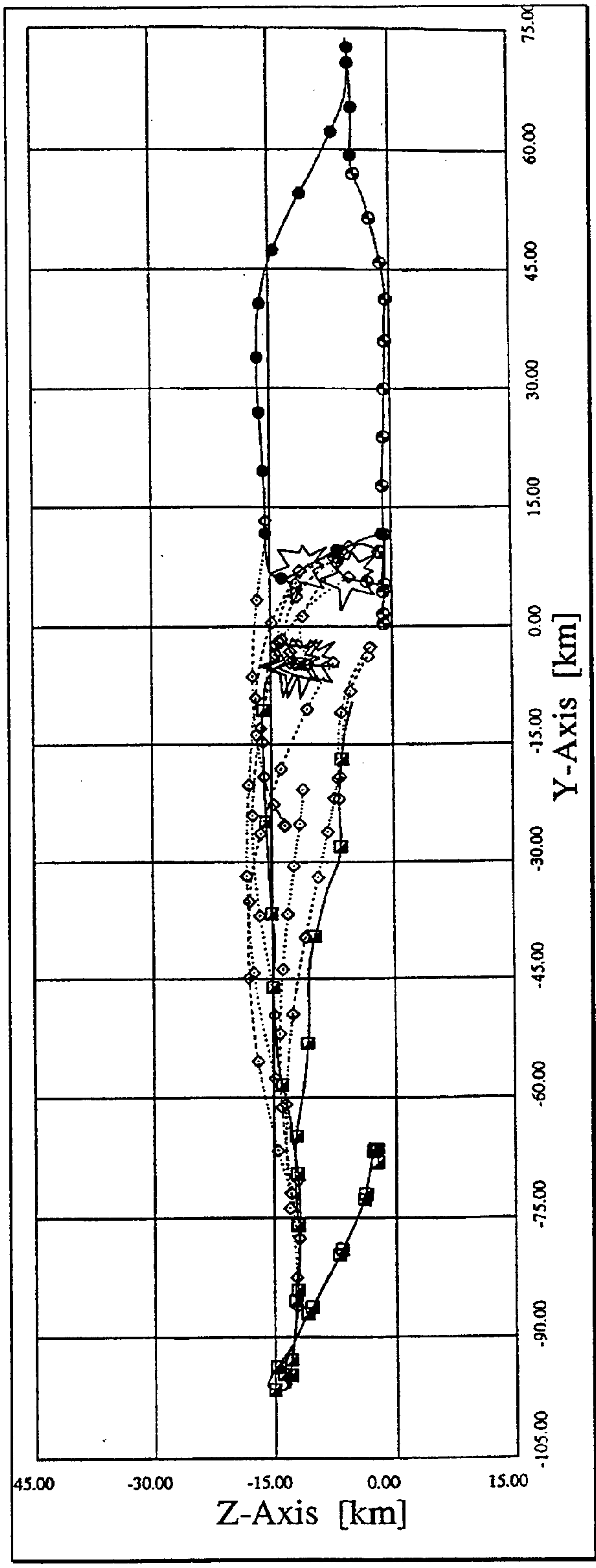


Fig. 12-2 R2 - Trajectory plot (Z-Y - Axis)

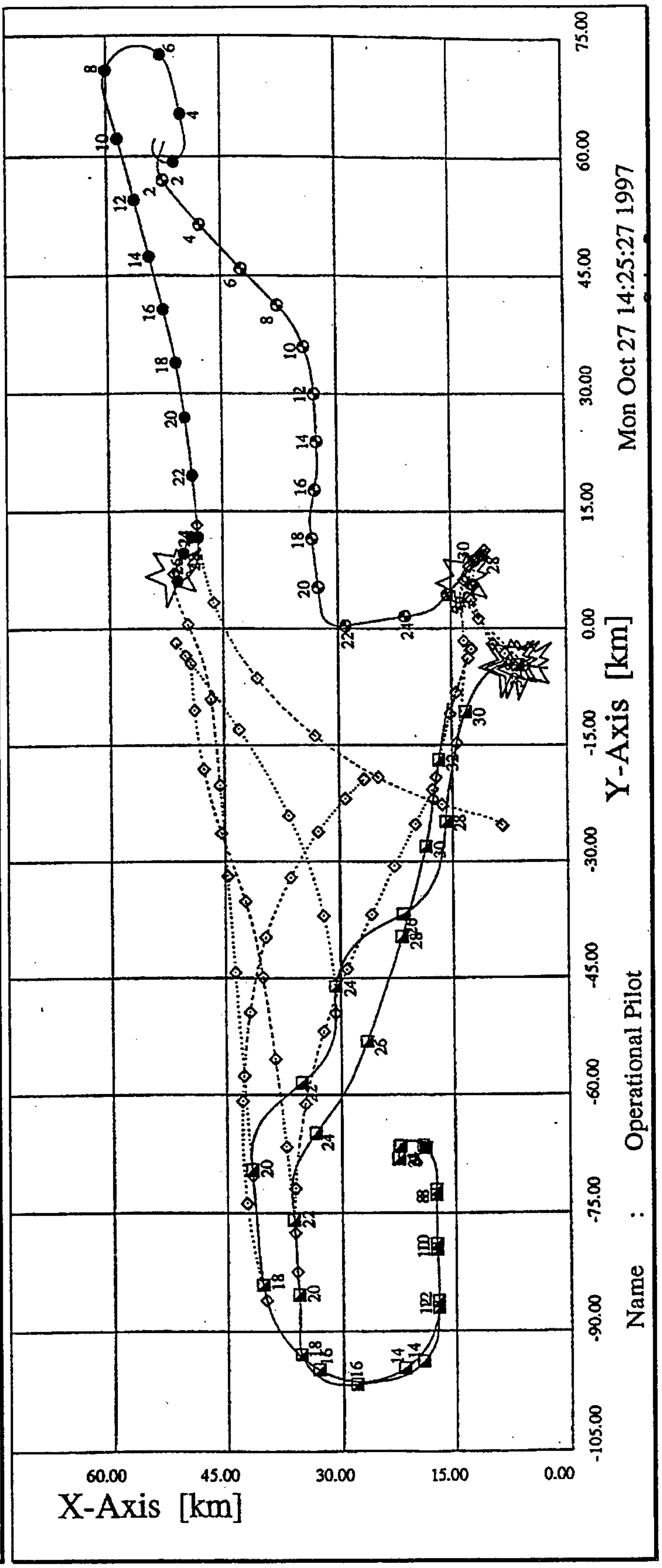


Fig. 12-3 R2 -Trajectory plot (X-Y - Axis)

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
ROT 1	FIGHTER	COCKPIT	334.	53.7 62.1 -4.6	0.69	290.	B2 236.0 297.0 687. -2 5						MRM
													SRM
BLAU 1	FIGHTER	COCKPIT	334.	22.5 -68.3 -2.2	0.00	0.	R2 207.0 287.0 32813. -2 2	R1 217.0 297.0 17346. -2 2	R2 311.0 333.0 10627. -2 -4	R2 316.0 333.0 10566. -2 -4			MRM
													SRM
BLAU 2	FIGHTER	COCKPIT	334.	22.5 -68.3 -2.2	0.00	0.	R2 177.0 255.0 25377. -2 5	R1 199.0 267.0 0. -3 0	R1 235.0 277.0 12556. -2 5	R2 294.0 313.0 0. -3 0			MRM
													SRM
ROT 2	FIGHTER	COCKPIT	334.	52.5 61.8 -4.6	0.68	290.	B2 292.0 317.0 0. -3 0	B2 296.0 319.0 0. -3 0	B2 303.0 324.0 0. -3 -2				MRM
													SRM

Fig. 12-4 R2 - Summary Table

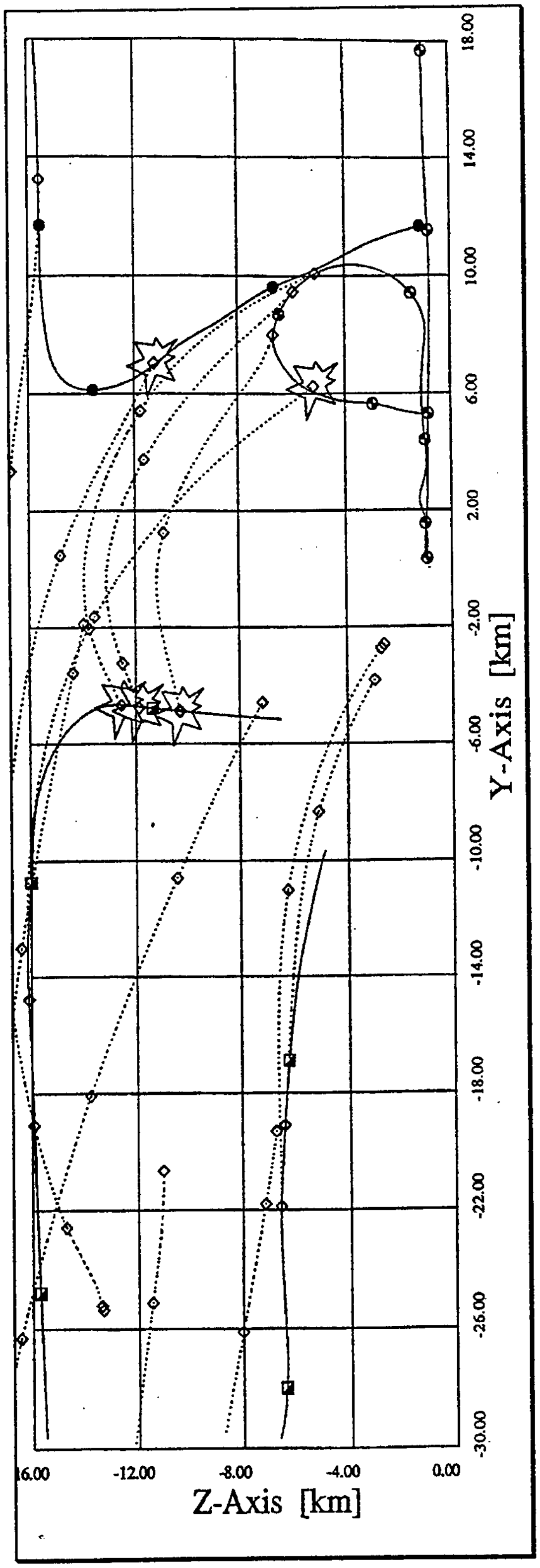


Fig. 12-5 R2 - Trajectory plot (Z-Y - Axis, „Blow Up")

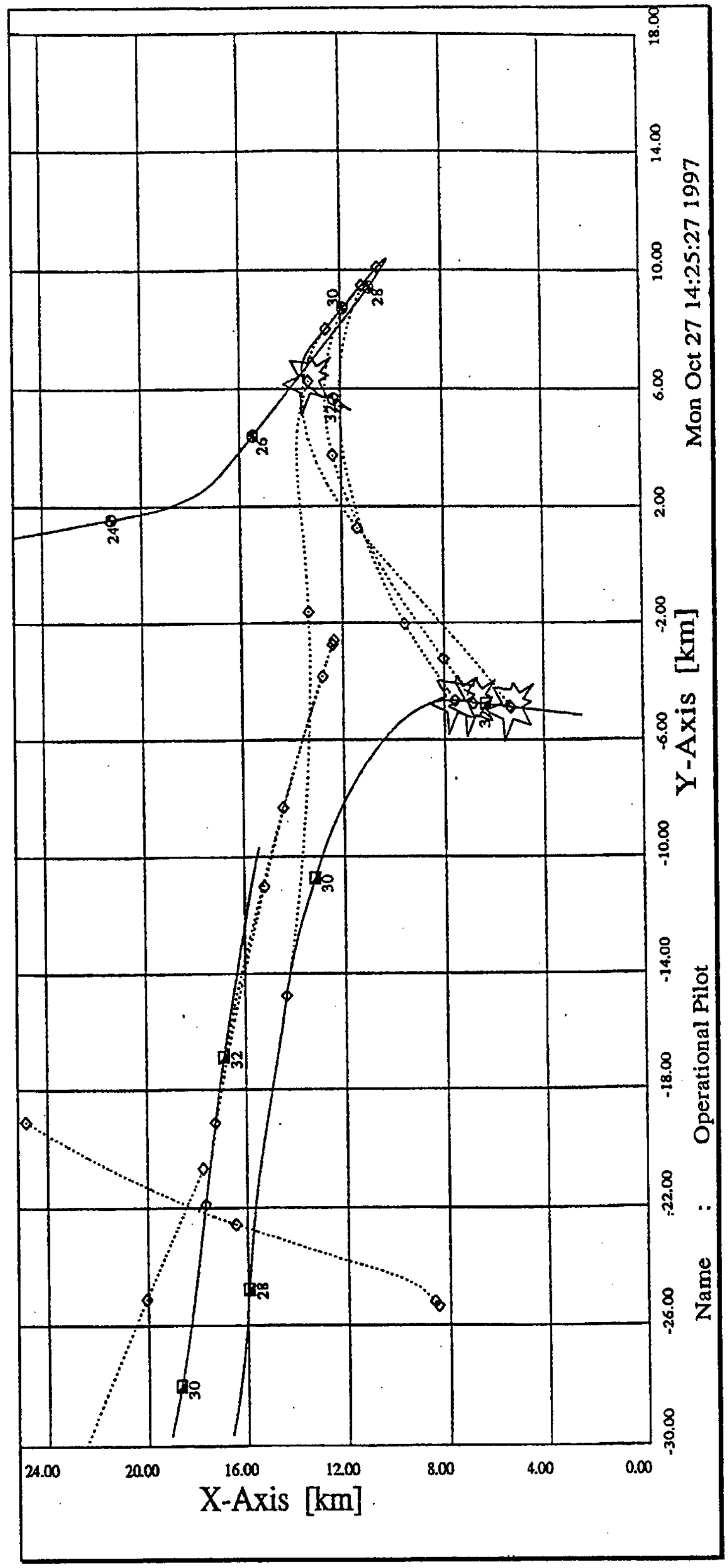


Fig. 12-6 R2 - Trajectory plot (X-Y - Axis, „Blow Up")

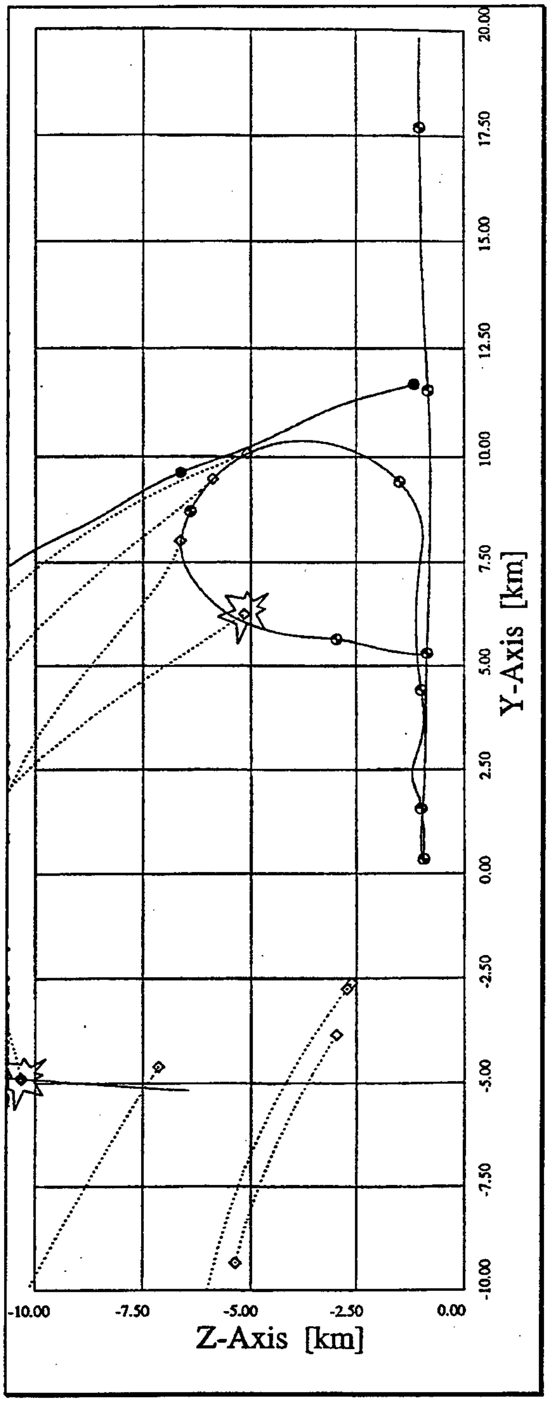


Fig. 12-8 R2 - Trajectory plot (Z-Y - Axis, „Blow Up“)

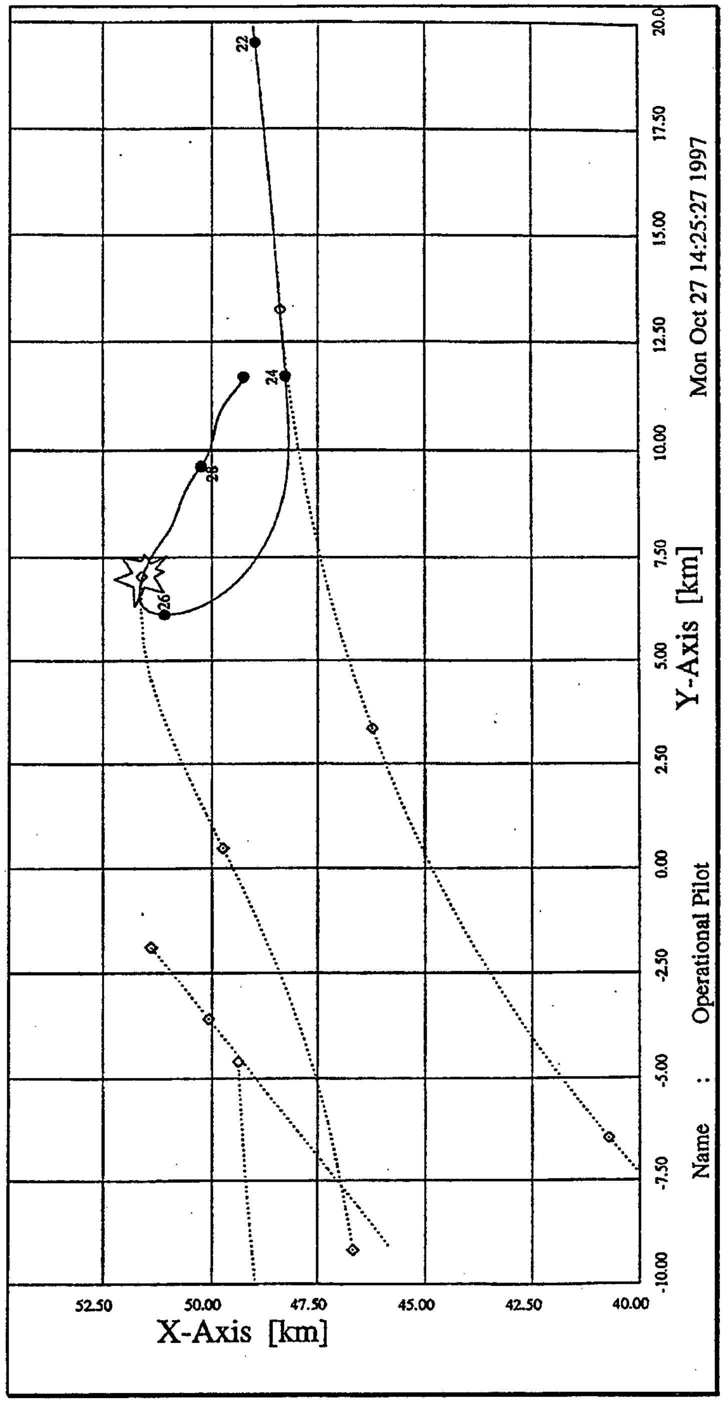


Fig. 12-7 R2 - Trajectory plot (X-Y - Axis, „Blow Up“)

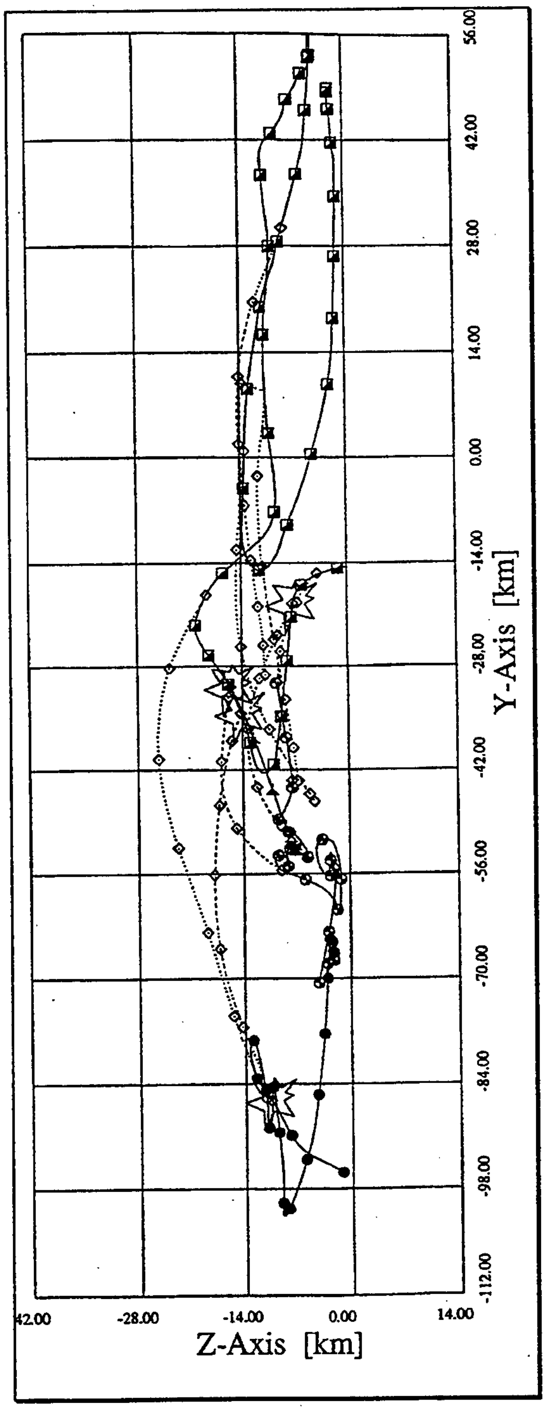


Fig. 12-10 R3 - Trajectory plot (Z-Y - Axis)

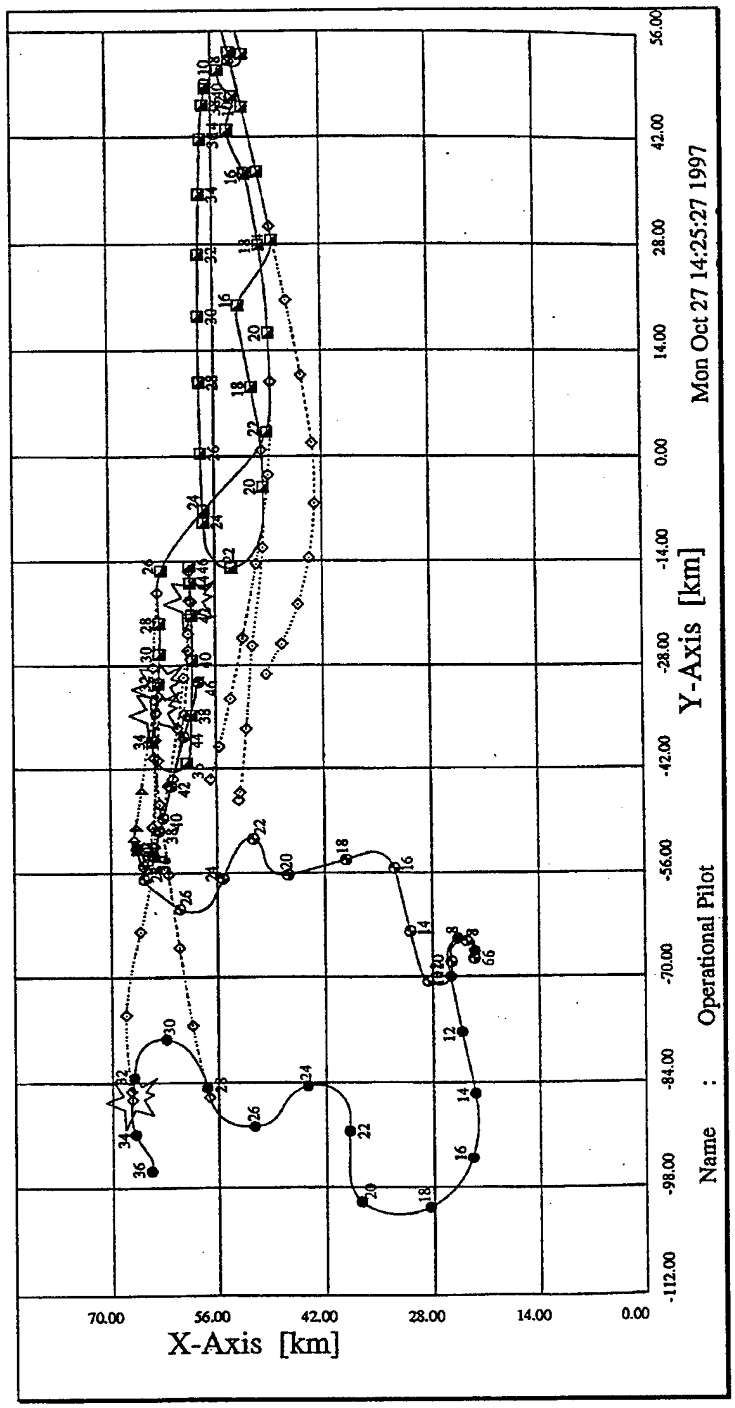


Fig. 12-9 R3 - Trajectory plot (X-Y - Axis)

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	463.	22.5 -67.7 -2.2	0.24	91.	R1 277.0 332.0 0. -3 0						MRM
													SRM
BLAU 2	FIGHTER	COCKPIT	463.	22.5 -68.1 -2.2	0.07	90.	R1 290.0 322.0 0. -3 0	R1 379.0 428.0 0. -3 0	R1 423.0 462.0 3495. -2 9				MRM
													SRM
ROT 1	FIGHTER	COCKPIT	463.	52.9 59.4 -4.5	0.62	288.	B2 210.0 269.0 17191. -2 5	B1 267.0 329.0 0. -3 0					MRM
									B2 316.0 350.0 2783. -2 -3				SRM
ROT 2	FIGHTER	COCKPIT	463.	54.0 60.0 -4.6	0.46	290.	B2 136.0 216.0 24085. -2 2	B2 193.0 235.0 9301. -2 5					MRM
													SRM

Fig. 12-11 R3 - Summary Table Run3

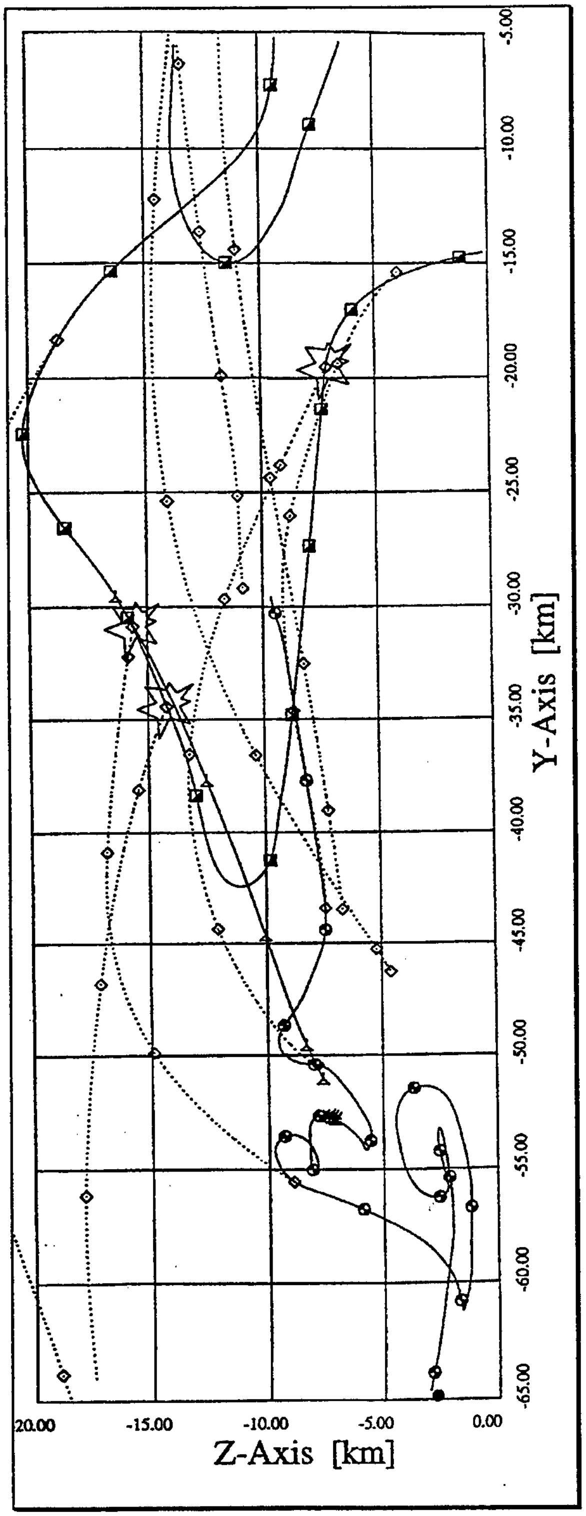


Fig. 12-12 R3 - Trajectory plot (Z-Y - Axis, „Blow Up“)

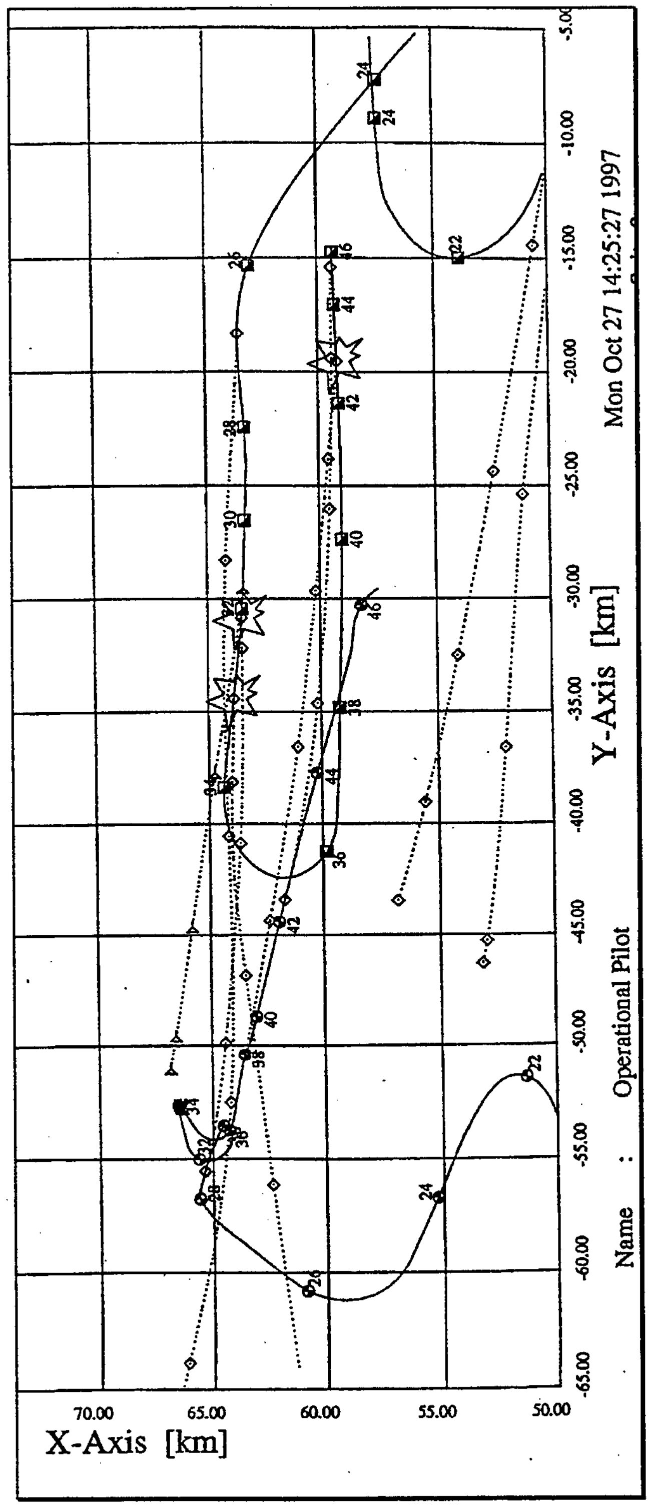


Fig. 12-13 R3 - Trajectory plot (X-Y - Axis, „Blow Up“)

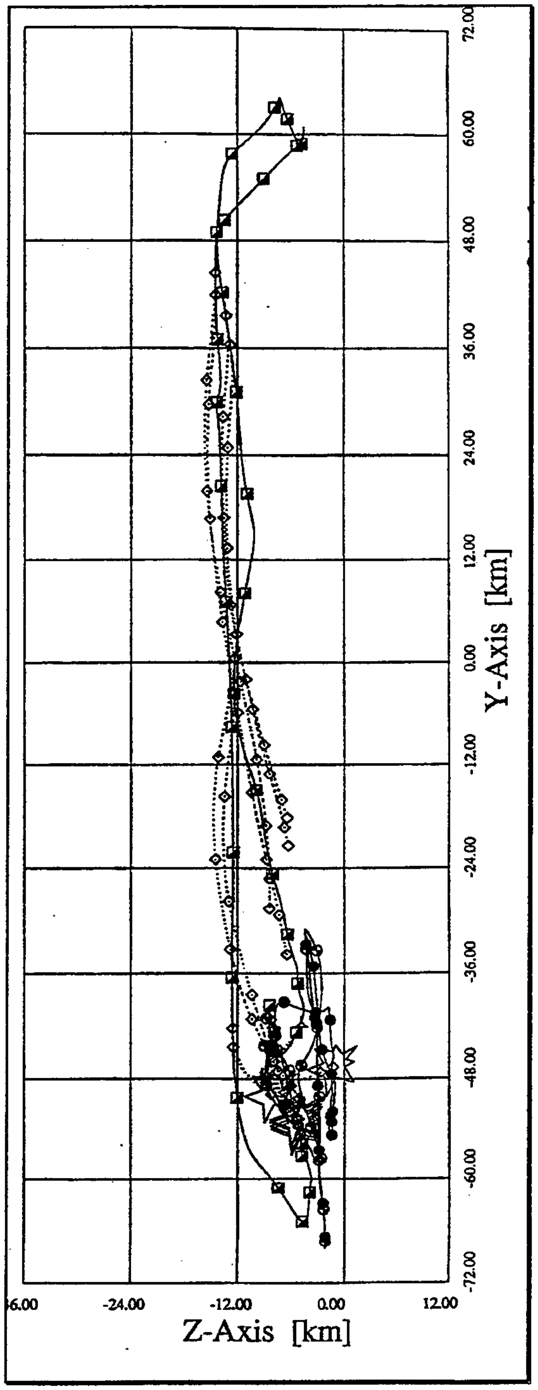


Fig. 12-15 R1 - Trajectory plot (Z-Y - Axis)

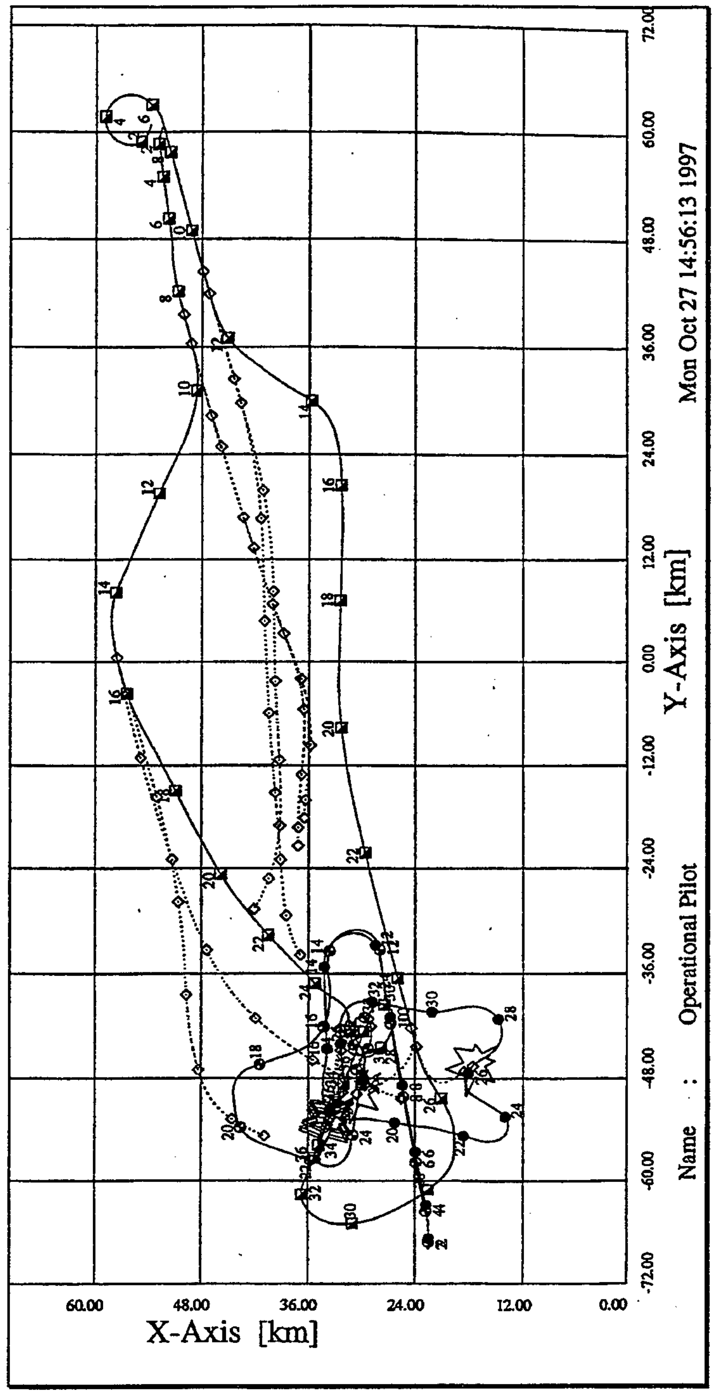


Fig. 12-14 R1 - Trajectory plot (X-Y - Axis)

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	360.	22.5 -67.8 -2.2	0.23	90.	R2 335.0 348.0 0. -3 0	R2 337.0 349.0 0. -3 0	R2 342.0 352.0 1. -3 0				MRM
													SRM
BLAU 2	FIGHTER	COCKPIT	360.	22.5 -68.0 -2.2	0.19	89.	R1 312.0 315.0 371. -2 0	R2 336.0 351.0 0. -3 0					MRM
													SRM
ROT 1	FIGHTER	COCKPIT	360.	52.5 60.5 -4.6	0.68	290.	B2 85.0 149.0 19720. -2 5	B2 91.0 155.0 19252. -2 5	B1 153.0 222.0 9675. -2 5	B2 160.0 218.0 5386. -2 5			MRM
							B2 256.0 267.0 990. -2 -3						SRM
ROT 2	FIGHTER	COCKPIT	360.	53.7 60.8 -4.6	0.68	290.	B2 108.0 186.0 19399. -2 5	B1 112.0 192.0 20818. -2 2	B2 248.0 258.0 0. -3 0	B1 251.0 263.0 0. -3 0			MRM
													SRM

Fig. 12-16 R1 - Summary Table

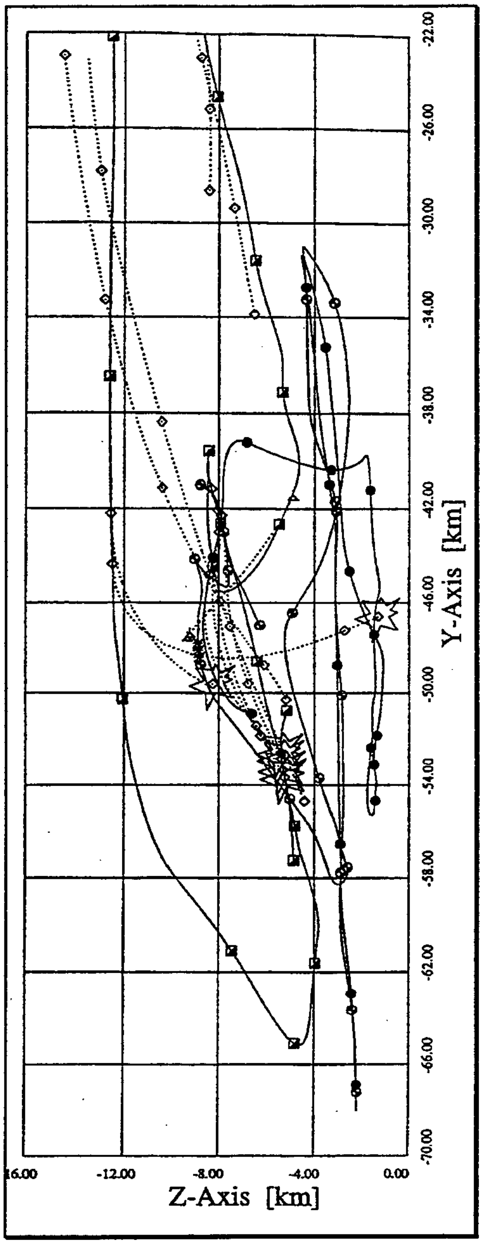


Fig. 12-17 R1 - Trajectory plot (Z-Y - Axis, „Blow Up")

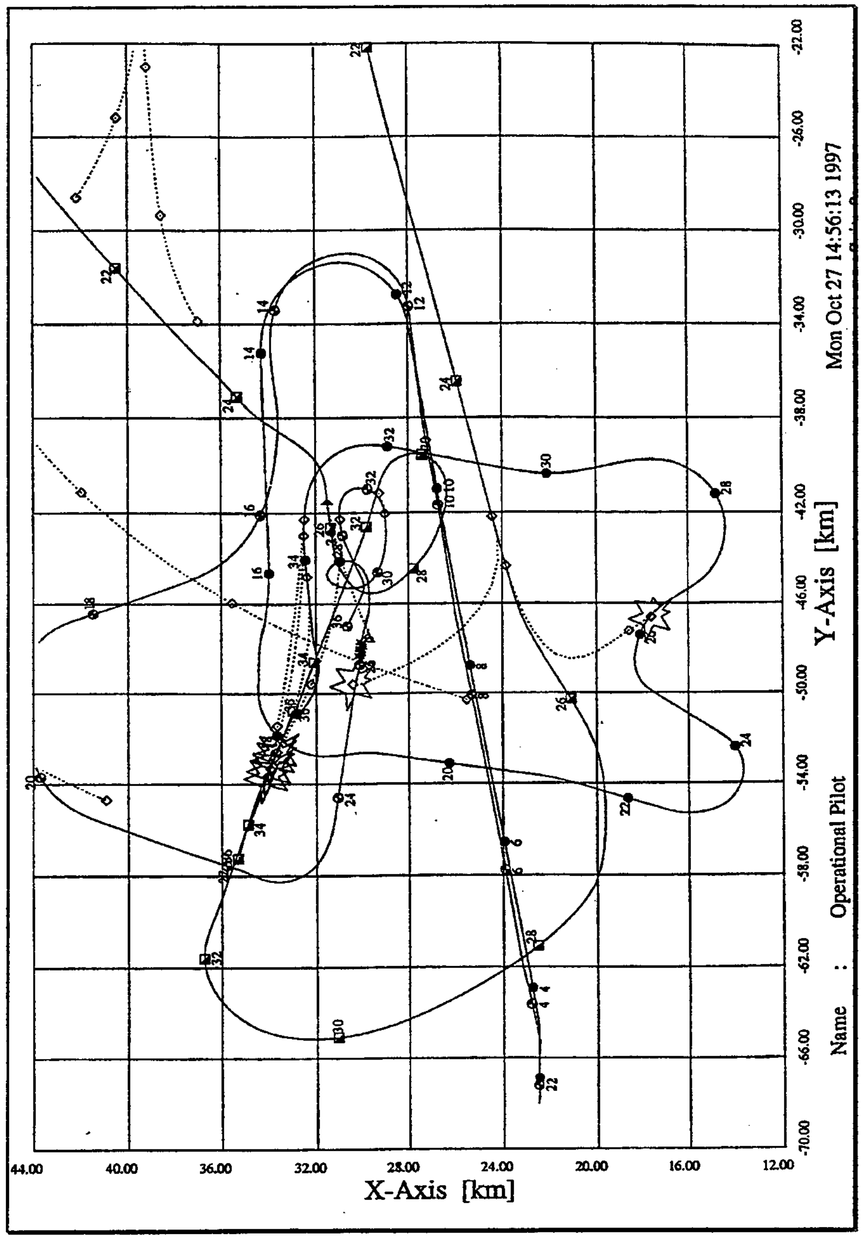


Fig. 12-18 R1 - Trajectory plot (X-Y - Axis, „Blow Up")

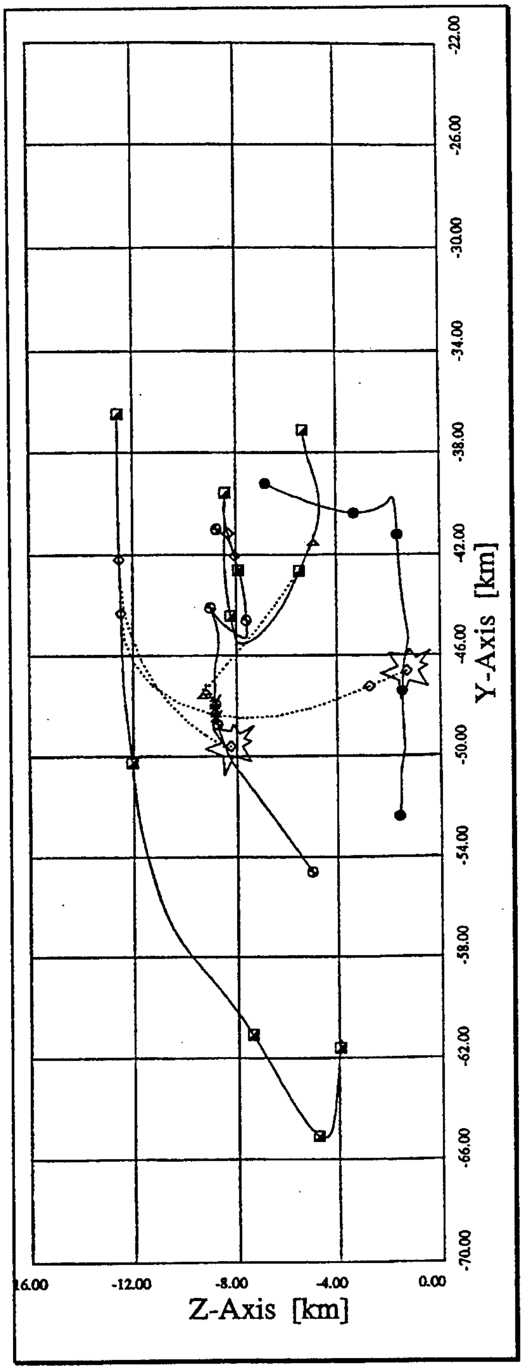


Fig. 12-20 R1 - Trajectory plot (Z-Y - Axis, „Blow Up")

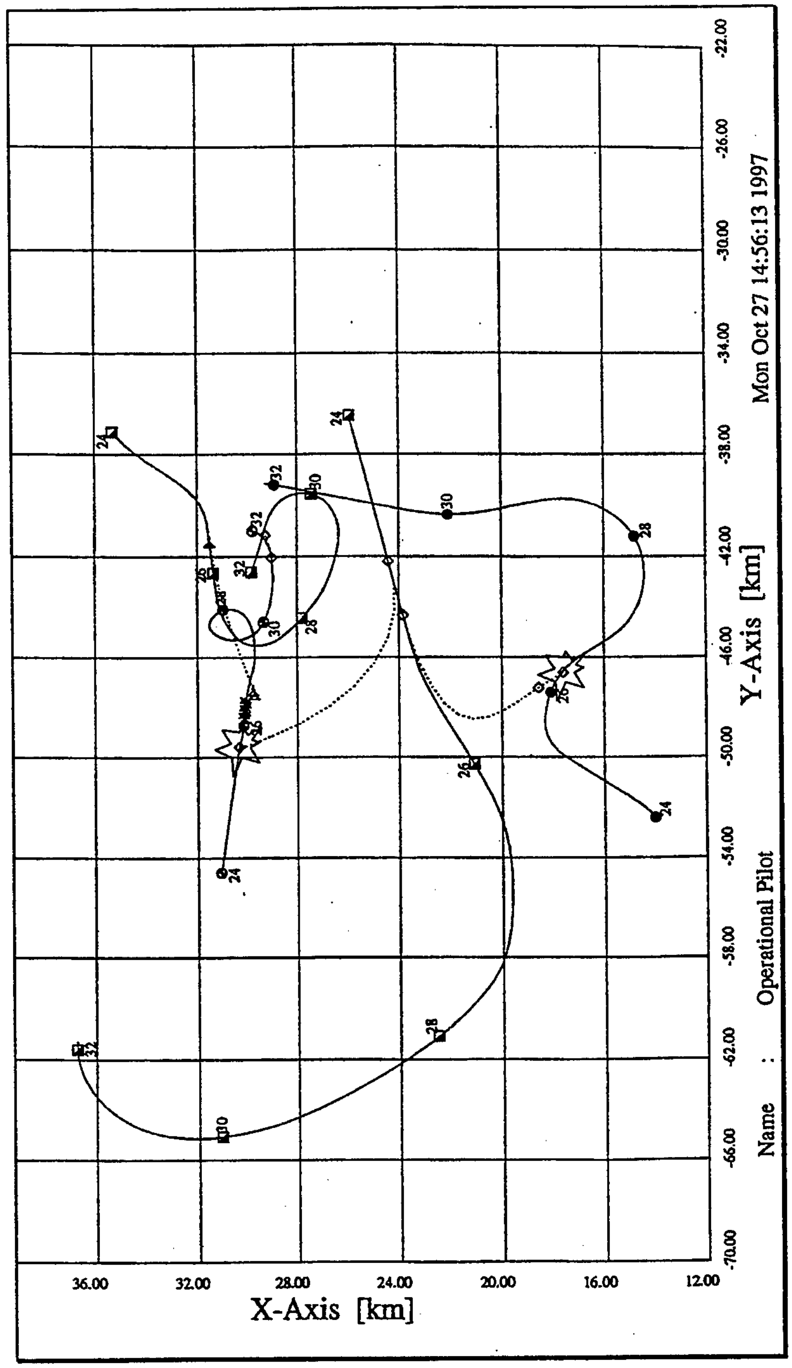


Fig. 12-19 R1 - Trajectory plot (X-Y - Axis, „Blow Up")

12.3 Evaluation of Scenario S5 Runs (Joint Mission Training)

Air Force Research Laboratory and DASA cockpits, on "blue side", start "line abreast" in 15000 ft at Ma = 0.67 with heading 090 (spacing between fighters : Blue 1 - Blue 2 = 2000 m, Blue 2 - Blue 3 = 2400 m, Blue 3 - Blue 4 = 2200 m).

Three CGT's in the role of „detached escorts" start about 80 nm east of the cockpits in 10000 ft at Ma = 0.66 and a heading of 268.

All fighters - cockpits or CGT - are equipped with 4 MRM, 4 SRM and 30 flares.

A further CGT in the role of „fighter bomber" starts in 4300 ft at Ma = 0.64 with a heading of 308.

The escorts maintain speed and altitude while heading for a waypoint located at the „Forward Line of Troops" (FLOT). After crossing the FLOT, they switch on their radars and initiate the engagement. If not destroyed, the engagement is ended when their remaining fuel reaches a predefined value. They will then disengage and return to their ingress corridor.

The bomber descends to low altitude, initiating „terrain following", trying to maintain a terrain clearance of 80 m. It follows a preprogrammed waypoint route (mission goal is to unload bombs on Nellis airbase) and returns to home base after mission completion.
Defensive maneuver is a „Doppler notch" maneuver when tracked from the front hemisphere. It reacquires its waypoint route if unthreatened or tracked from the back hemisphere. Weapons carried are 4 SRM which will be employed if chances for opponent kill is high (it will then switch on its radar and fire on opponent; return to mission if Short Range engagement is finished). In case a missile (MRM or SRM) is fired on it, bombs will be dropped and an avoidance maneuver is performed. If missile is successfully avoided, the bomber will disengage and return to home base.

- Run of Wed Oct 29 13:47:35 1997
  (Fig. 12-21 to Fig. 12-24; „blow up" plots in Fig. 12-25 Fig. 12-30)

Summary of outcome :

Blue 1 :	hits bomber at t = 474 sec survives engagement
Blue 2 :	hits Red 2 at t = 345 sec hit by Red 2 at t = 371 sec → „mutual kill" barely missed by Red 1 at t = 379 sec while crashing
Blue 3 :	hits Red 3 at t = 678 sec survives engagement
Blue 4 :	hit by Red 3 at t = 314 sec
Red 1 :	no target hits survives engagement
Red 2 :	hit by Blue 2 at t = 345 sec hit Blue 2 at t = 371 sec --→ „mutual kill"
Red 3 :	hit Blue 4 at t = 314 sec hit by Blue 3 at t = 678 sec
Red 4 :	hit by Blue 1 at t = 474 sec

- Run of Wed Oct 29 14:13:25 1997
  (Fig. 12-31 to Fig. 12-34; „blow up" plots in Fig. 12-35 and Fig. 12-36)

Summary of outcome :

Blue 1 :	no target hits survives engagement
Blue 2 :	hits Red 1 at t = 422 sec hits Red 2 at t = 425 sec hits Red 4 at t = 421 sec survives engagement
Blue 3 :	hits Red 3 at t = 365 sec survives engagement
Blue 4 :	no target hits survives engagement
Red 1 :	no target hits hit by Blue2 at t = 422 sec
Red 2 :	no target his hit by Blue2 at t = 425 sec
Red 3 :	no target his hit by Blue3 at t = 422 sec
Red 4 :	no target his hit by Blue2 at t = 421 sec

- Run of Wed Oct 29 15:08:51 1997
  (Fig. 12-37 to Fig. 12-40; „blow up" plots in Fig. 12-41 to Fig. 12-45)

Summary of outcome :

Blue 1 :	hits Red 2 at t = 432 sec with SRM defeats SRM of Red 2 at t = 432 sec through use of flares hit by Red 1 at t = 451 sec
Blue 2 :	hits Red 4 at t = 292 sec survives engagement
Blue 3 :	no target hits survives engagement
Blue 4 :	hits Red 3 at t = 478 sec hit by Red 1 at t = 469 sec
Red 1 :	hits Blue 1 at t = 451 sec hits Blue 4 at t = 469 sec
Red 2 :	no target hits hit by Blue 1 at t = 432 sec with SRM
Red 3 :	no target hits hit by Blue 4 at t = 478 sec
Red 4 :	hit by Blue 2 at t = 292 sec

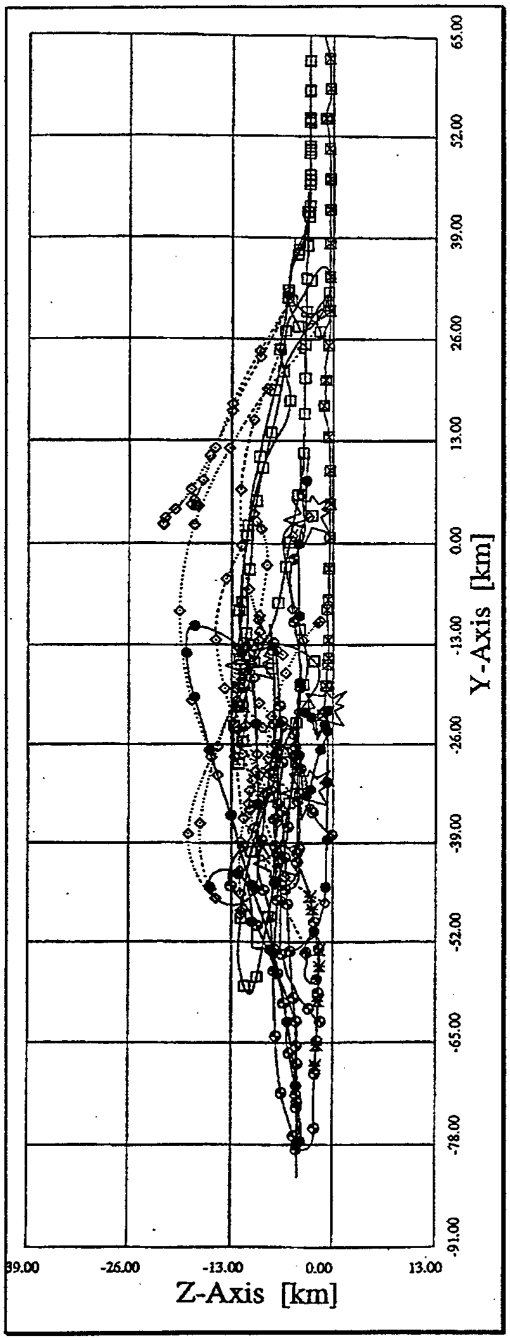


Fig. 12-21 R1 - Trajectory Plot (Z-Y Axis)

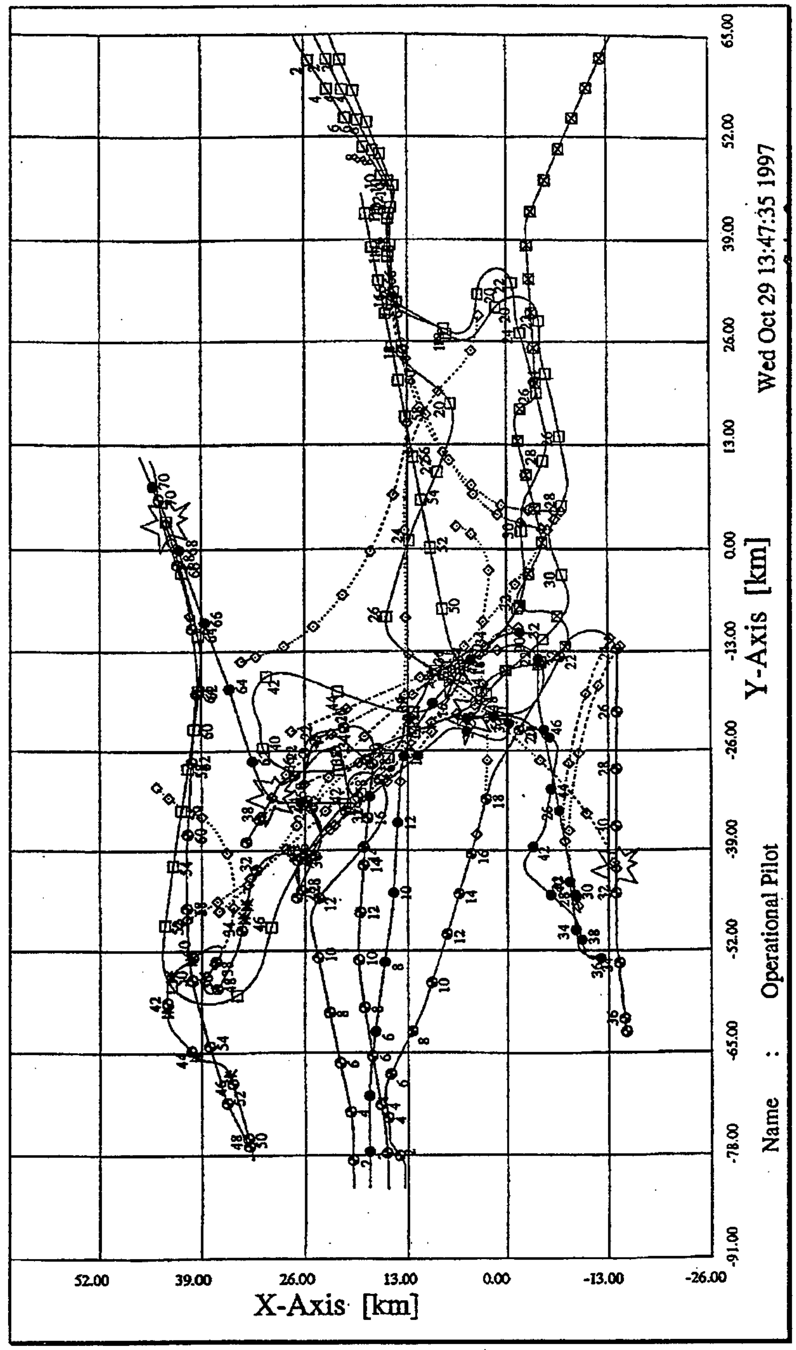


Fig. 12-22 R1 - Trajectory Plot (X-Y Axis)

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	712.	18.0 -82.2 -4.6	0.67	90.	R2 132.0 201.0 3261. -2 5	R3 294.0 334.0 5398. -2 5	R3 299.0 337.0 7806. -2 5	R4 461.0 474.0 0. -3 0			MRM
													SRM
BLAU 2	FIGHTER	COCKPIT	712.	15.6 -82.2 -4.6	0.00	90.	R2 312.0 345.0 0. -3 0	R4 314.0 368.0 2995. -2 5					MRM
													SRM
BLAU 3	FIGHTER	COCKPIT	712.	20.0 -82.2 -4.6	0.00	90.	R1 379.0 424.0 21622. -2 5	R3 664.0 678.0 0. -3 0					MRM
													SRM
BLAU 4	FIGHTER	COCKPIT	712.	13.4 -82.2 -4.6	0.67	90.	R3 168.0 224.0 6068. -2 -1						MRM
													SRM
ROT 1	DESCORT	CGT	712.	22.9 65.6 -3.1	0.66	268.	B1 155.0 228.0 23310. -2 5	B3 284.0 340.0 20120. -2 5	B2 349.0 379.0 145. -2 -1	B3 375.0 404.0 8177. -2 8			MRM
													SRM

Fig. 12-23 R1 - Summary Table

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	712.	18.0 -82.2 -4.6	0.67	90.	R2 132.0 201.0 3261. -2 5	R3 294.0 334.0 5398. -2 5	R3 299.0 337.0 7806. -2 5	R4 461.0 474.0 0. -3 0			MRM
													SRM
ROT 2	DESCORT	CGT	712.	24.7 65.6 -3.1	0.66	268.	B1 159.0 232.0 24501. -2 5	B2 335.0 371.0 0. -3 0					MRM
													SRM
ROT 3	DESCORT	CGT	712.	27.2 65.3 -3.1	0.66	268.	B2 179.0 257.0 26587. -2 2	B4 272.0 314.0 0. -3 0	B2 334.0 364.0 7152. -2 8	B3 383.0 446.0 20286. -2 5			MRM
													SRM
ROT 4	BOMBER	CGT	712.	-14.1 65.7 -1.3	0.64	308.							MRM
													SRM

Fig. 12-24 R1 - Summary Table (cont.)

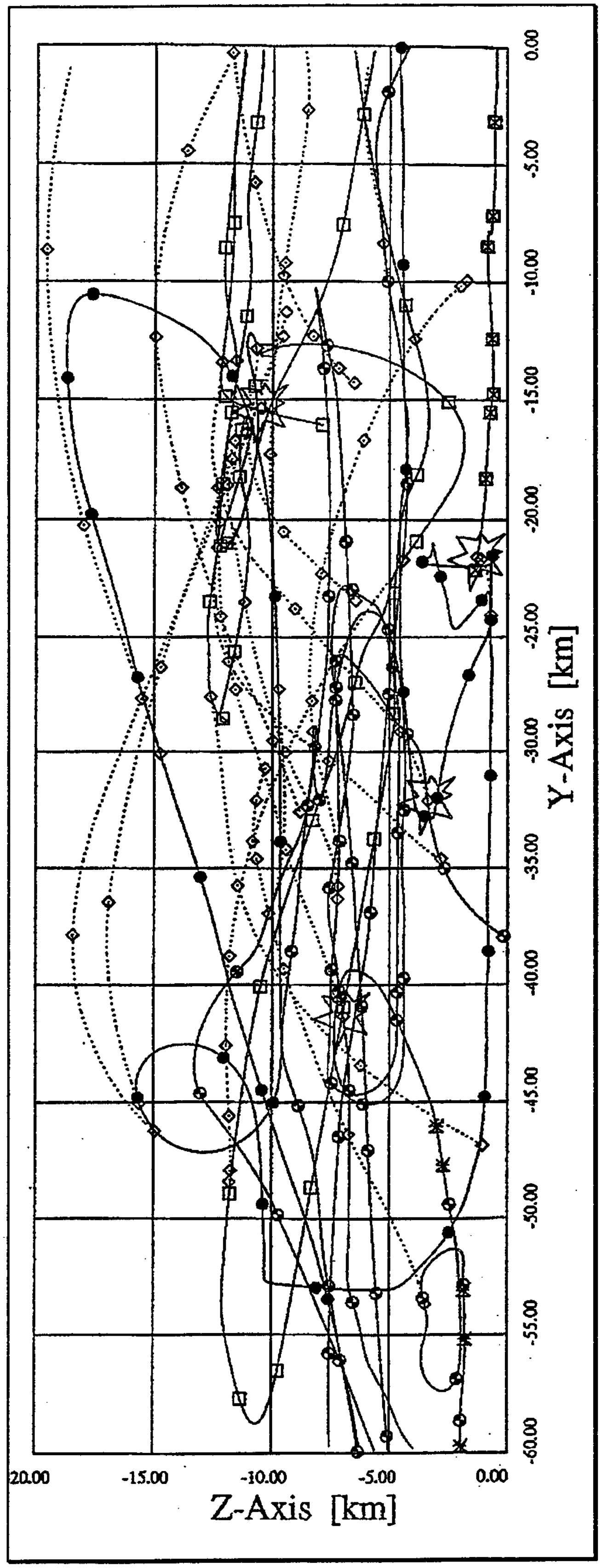


Fig. 12-25 R1 - Trajectory Plot (Z-Y Axis, „Blow Up“)

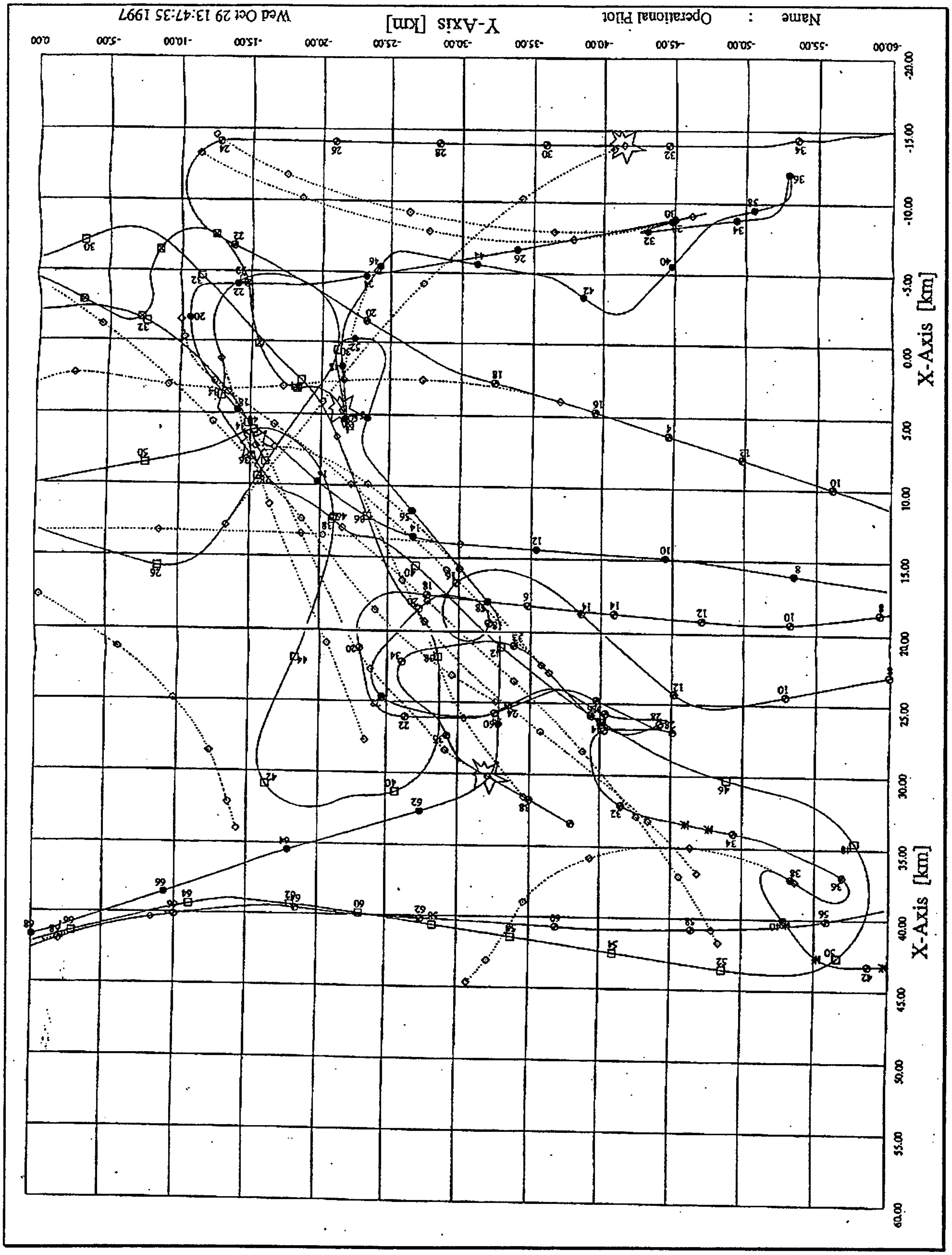
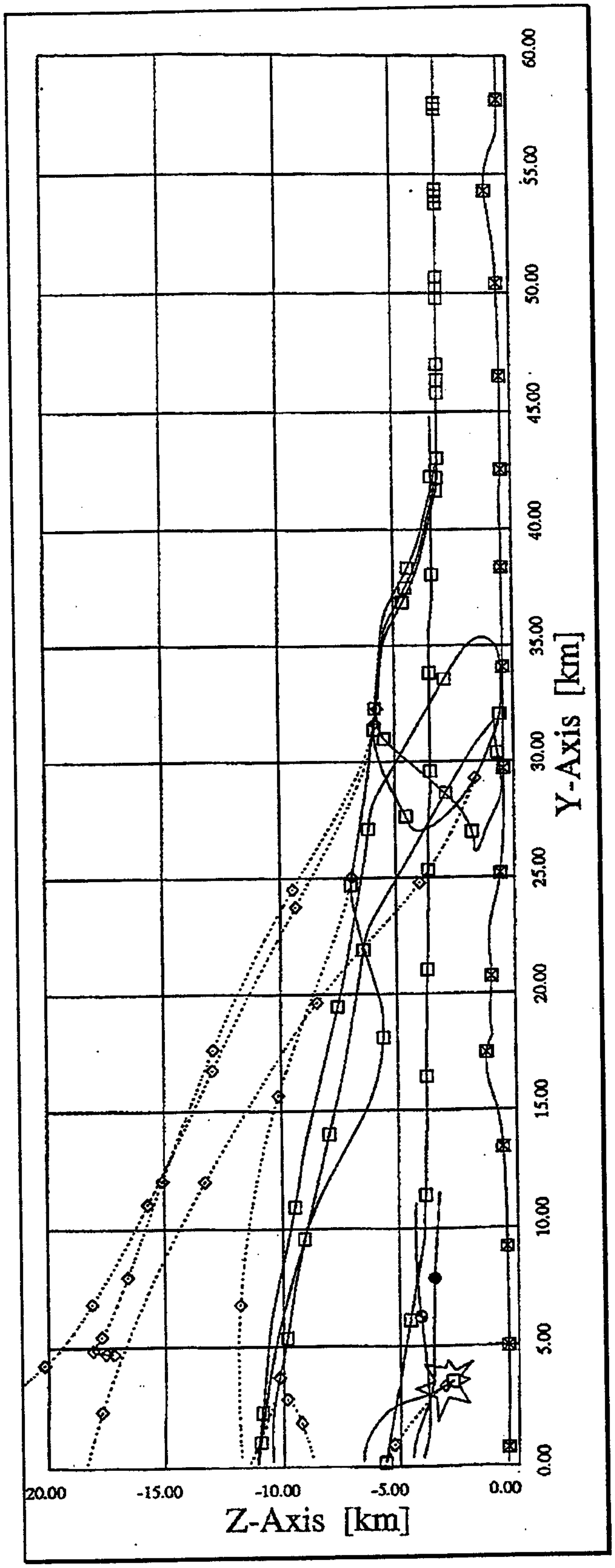


Fig. 12-26 R1 - Trajectory Plot (X-Y Axis, „Blow Up")


Z-Axis [km]
20.00
-15.00
-10.00
-5.00
0.00
Y-Axis [km]
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00

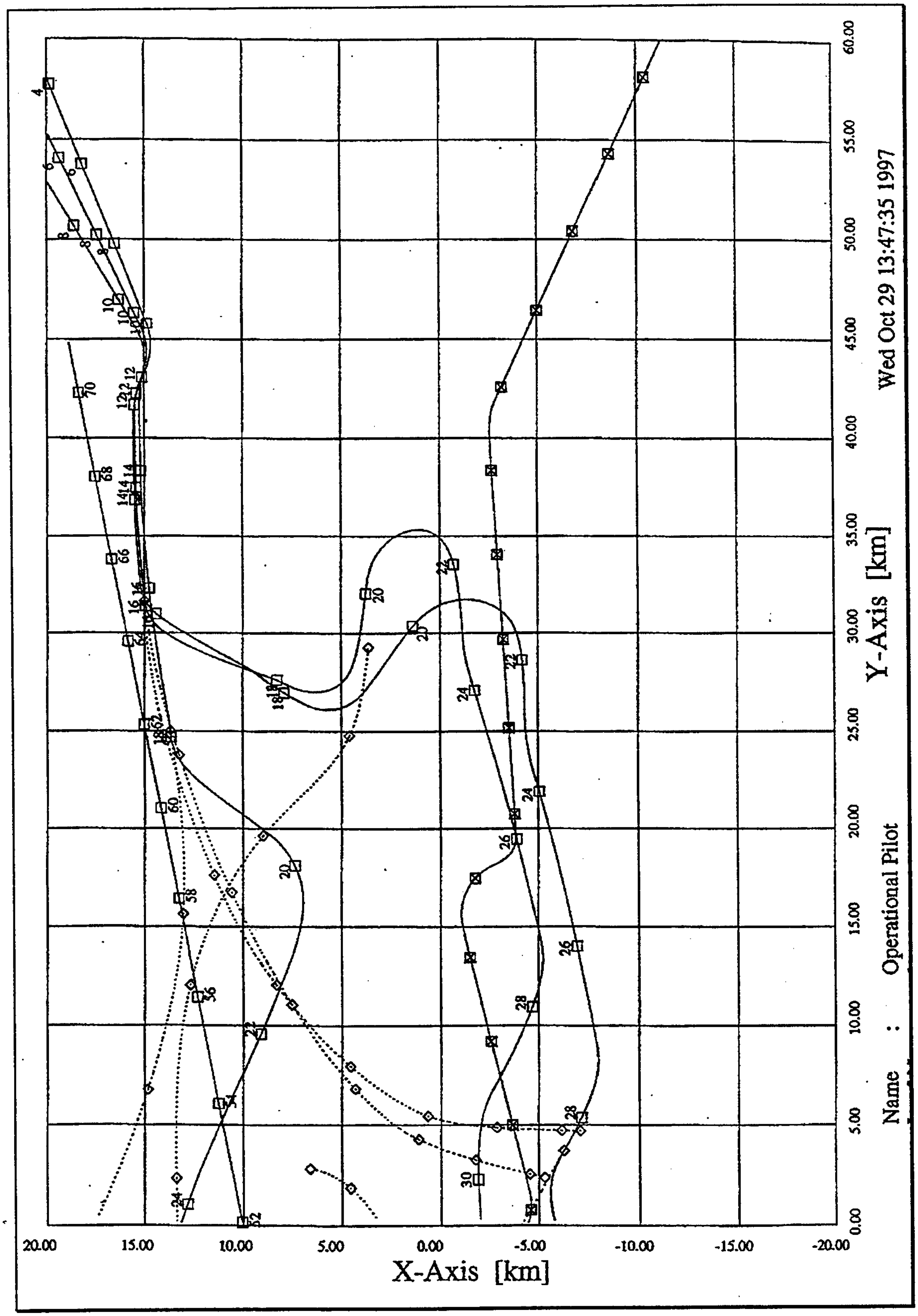


Fig. 12-28 R1 - Trajectory Plot (X-Y Axis, „Blow Up")

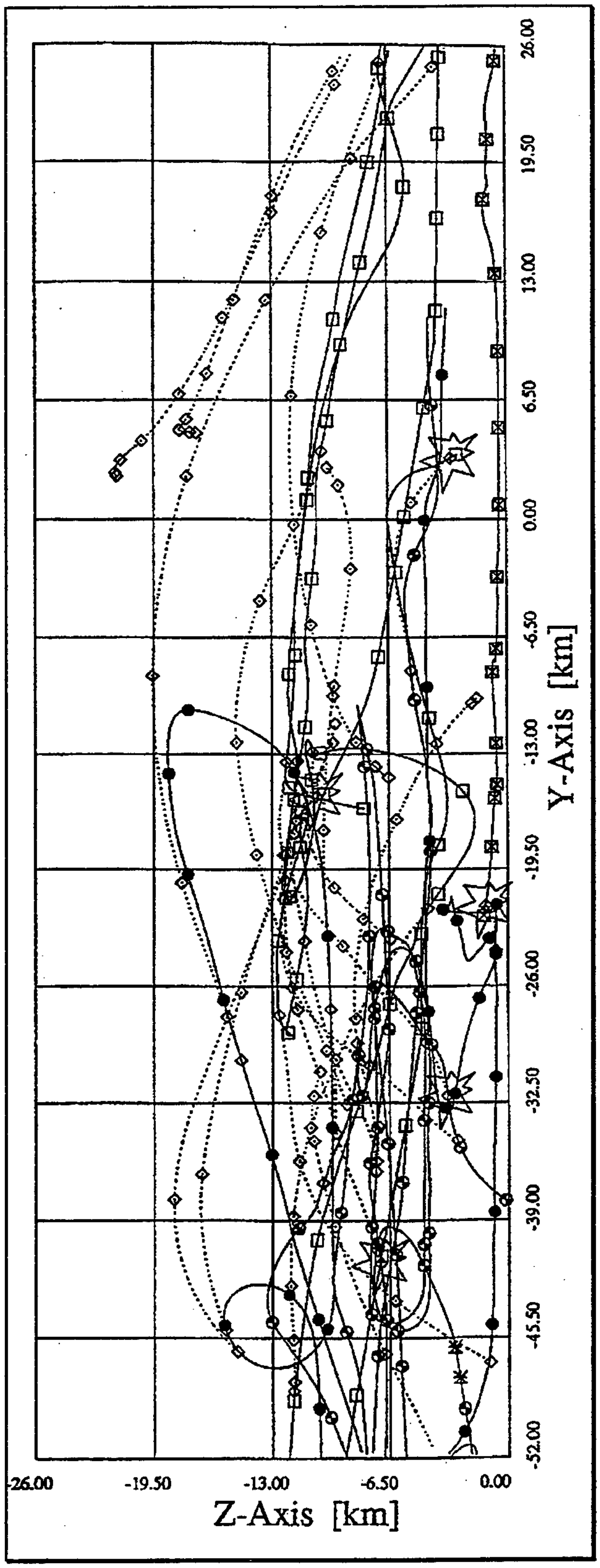


Fig. 12-29 R1 - Trajectory Plot (Z-Y Axis,"Blow Up")

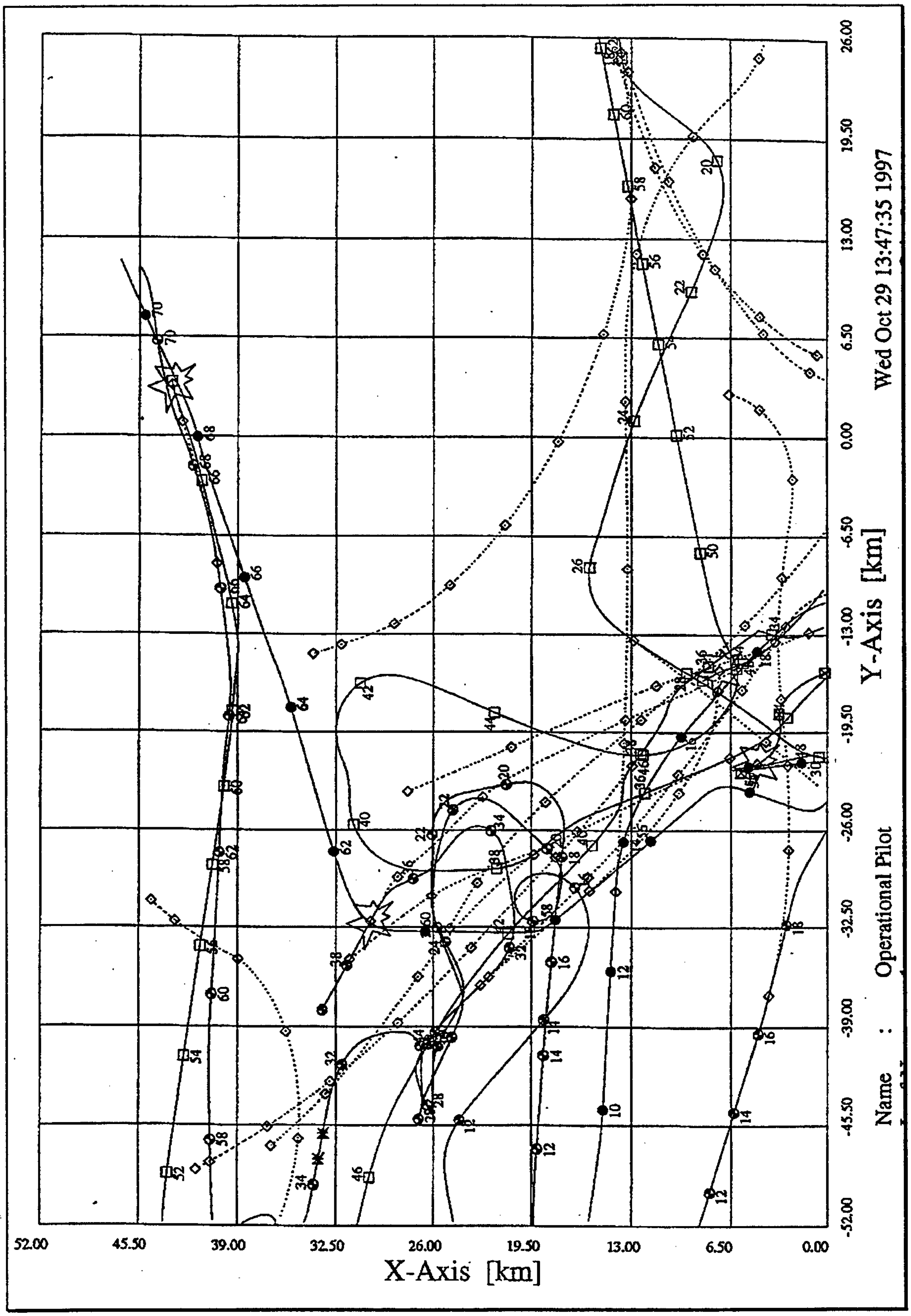


Fig. 12-30 R1 - Trajectory Plot (X-Y Axis,"Blow Up")

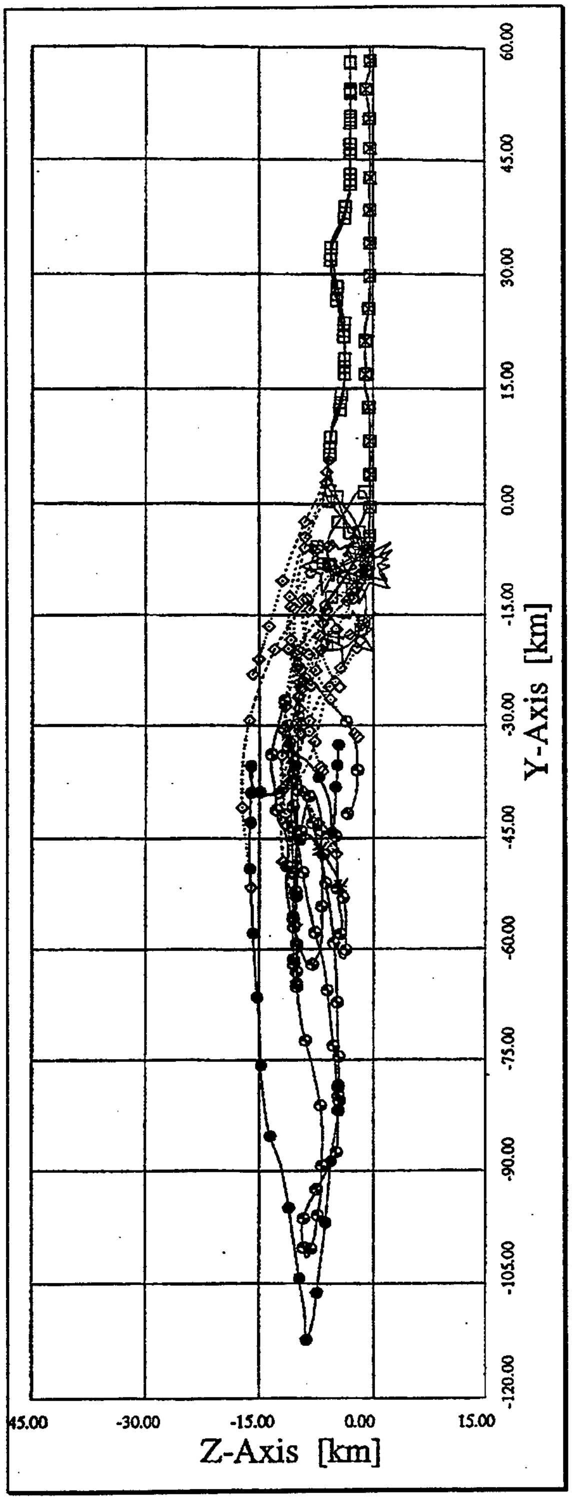


Fig. 12-31 R2 - Trajectory Plot (Z-Y Axis)

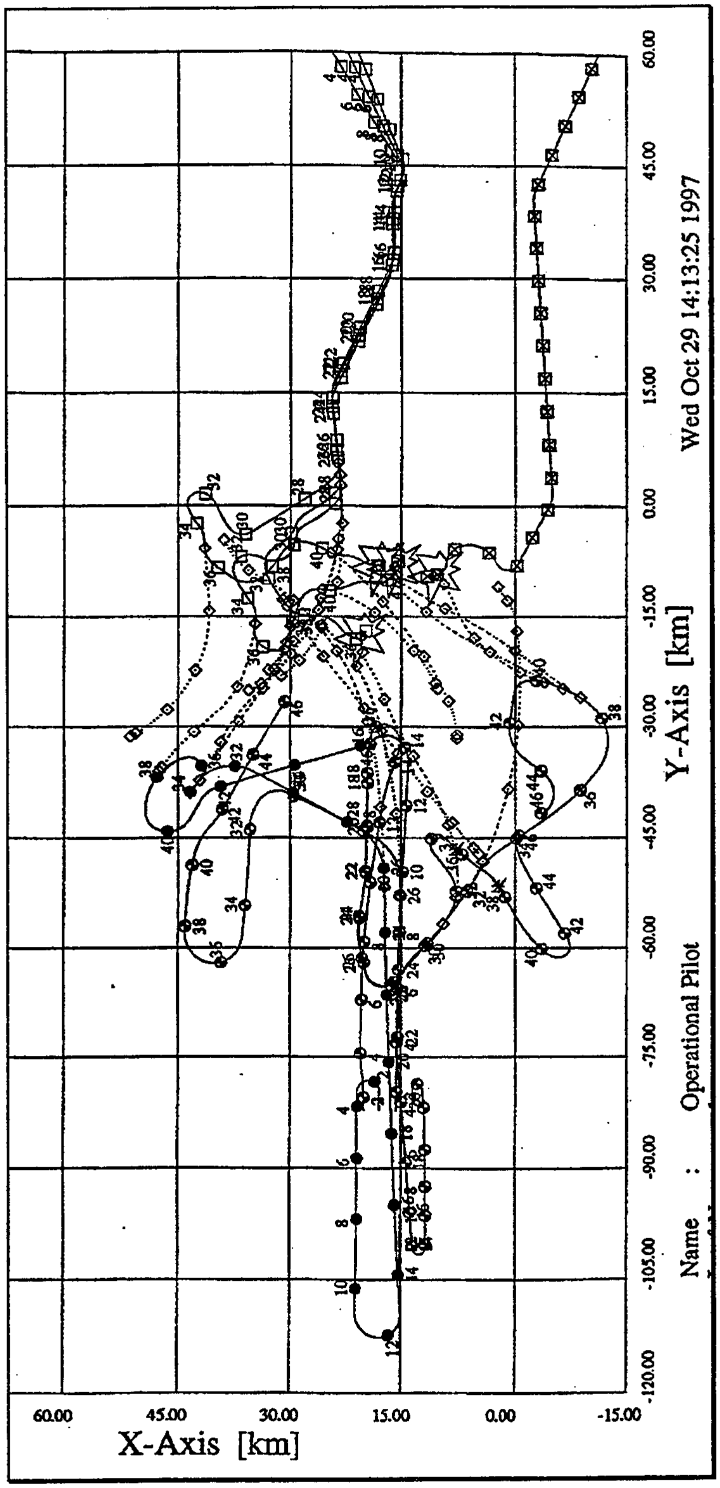


Fig. 12-32 R2 - Trajectory Plot (X-Y Axis)

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	460.	18.0 -82.2 -4.6	0.67	90.	R1 254.0 314.0 4742. -2 5	R2 347.0 379.0 2562. -2 5	R2 354.0 386.0 2341. -2 5				MRM
													SRM
BLAU 2	FIGHTER	COCKPIT	460.	15.6 -82.2 -4.6	0.00	0.	R4 308.0 374.0 3504. -2 5	R1 388.0 422.0 0. -3 0	R2 393.0 425.0 0. -3 0	R4 398.0 421.0 0. -3 -2			MRM
													SRM
BLAU 3	FIGHTER	COCKPIT	460.	20.0 -82.2 -4.6	0.00	0.	R3 318.0 365.0 0. -3 -2						MRM
													SRM
BLAU 4	FIGHTER	COCKPIT	460.	13.4 -82.2 -4.6	0.67	90.	R2 260.0 312.0 6420. -2 5						MRM
													SRM
ROT 1	DESCORT	CGT	460.	22.9 65.6 -3.1	0.66	268.	B1 262.0 310.0 13939. -2 -1	B1 351.0 393.0 12129. -2 5	B2 403.0 445.0 13809. -2 5				MRM
													SRM

Fig. 12-33 R2 - Summary Table

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	460.	18.0 -82.2 -4.6	0.67	90.	R1 254.0 314.0 4742. -2 5	R2 347.0 379.0 2562. -2 5	R2 354.0 386.0 2341. -2 5				MRM
													SRM
ROT 2	DESCORT	CGT	460.	24.7 65.6 -3.1	0.66	268.	B4 273.0 317.0 17572. -2 5	B1 351.0 383.0 2101. -2 5	B2 397.0 429.0 13362. -2 5				MRM
													SRM
ROT 3	DESCORT	CGT	460.	27.2 65.3 -3.1	0.66	268.	B4 273.0 312.0 18216. -2 5	B3 333.0 396.0 13848. -2 5					MRM
													SRM
ROT 4	BOMBER	CGT	460.	-14.1 65.7 -1.3	0.64	308.							MRM
													SRM

Fig. 12-34 R2.-. Summary Table (cont.)

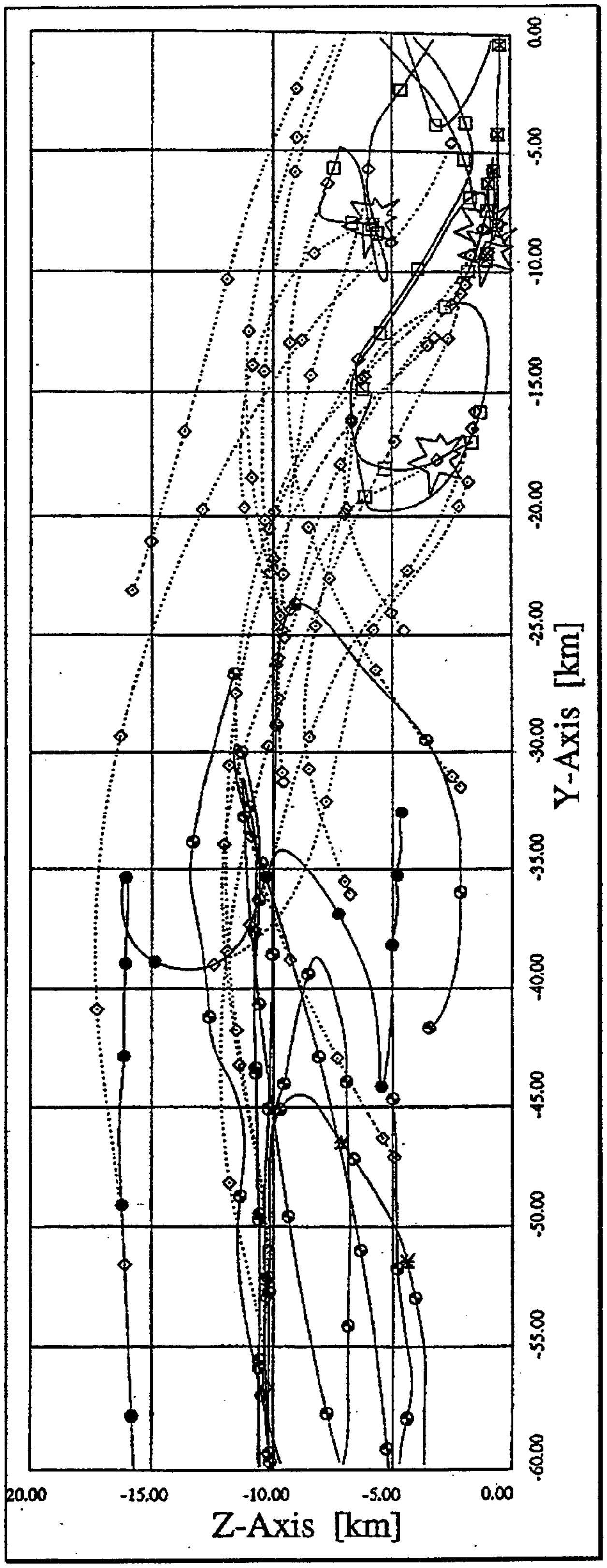


Fig. 12-35 R2 - Trajectory Plot (Z-Y Axis,"Blow Up")

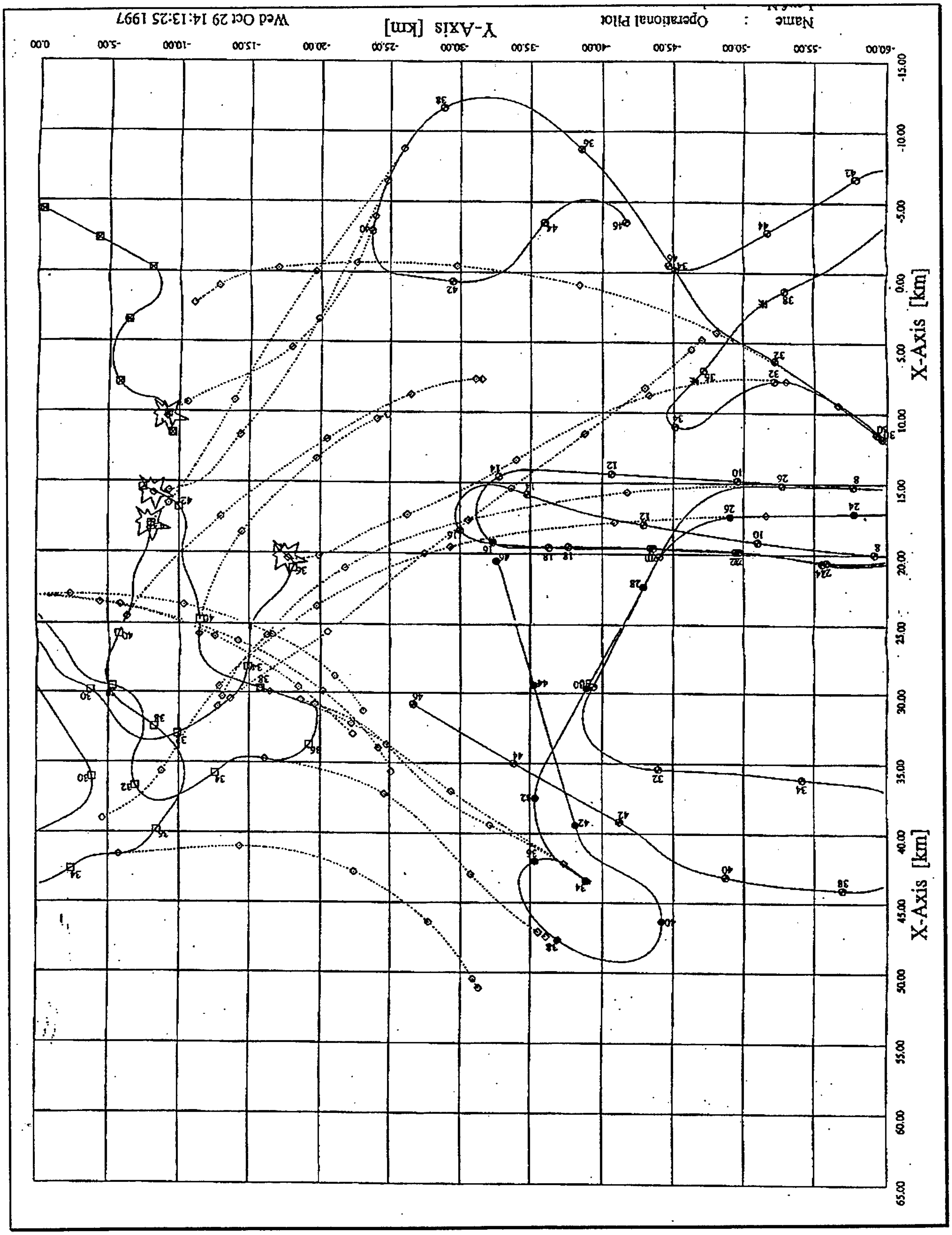


Fig. 12-36 R2 - Trajectory Plot (X-Y Axis,"Blow Up")

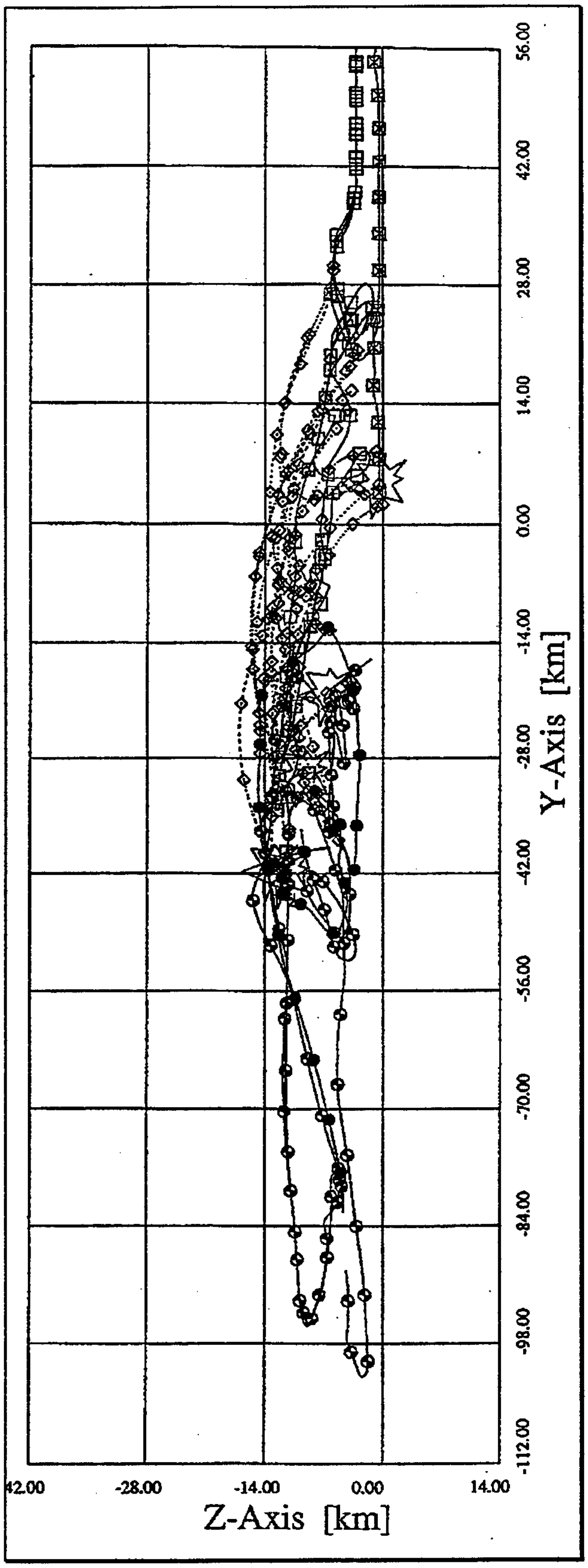


Fig. 12-37 R3 - Trajectory Plot (Z-Y Axis)

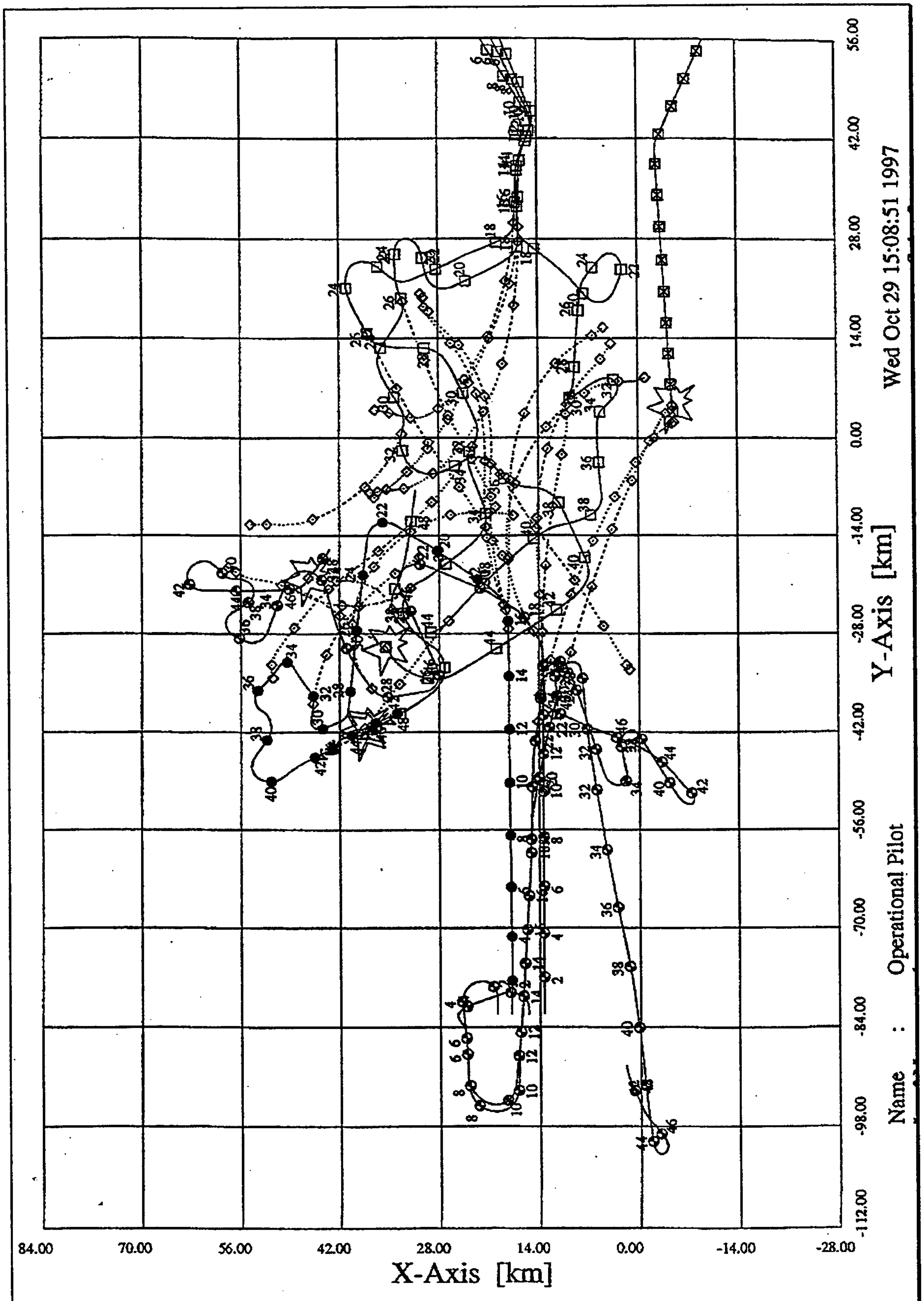


Fig. 12-38 R3 - Trajectory Plot (X-Y Axis)

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	490.	18.0 -82.2 -4.6	0.68	90.	R1 157.0 211.0 5060. -2 5	R3 164.0 218.0 5158. -2 5	R3 166.0 220.0 5316. -2 5	R3 316.0 353.0 19735. -2 5			MRM
							R2 423.0 432.0 3. -3 0						SRM
BLAU 2	FIGHTER	COCKPIT	490.	15.6 -82.2 -4.6	0.00	90.	R4 227.0 292.0 0. -3 -2						MRM
													SRM
BLAU 3	FIGHTER	COCKPIT	490.	20.0 -82.2 -4.6	0.00	90.	R4 229.0 301.0 99999. -2 -4	R1 242.0 299.0 1024. -2 5					MRM
													SRM
BLAU 4	FIGHTER	COCKPIT	490.	13.4 -82.2 -4.6	0.69	90.	R1 161.0 216.0 9466. -2 5	R1 174.0 235.0 17900. -2 5	R2 286.0 344.0 5085. -2 6	R3 459.0 478.0 0. -3 0			MRM
													SRM
ROT 1	DESCORT	CGT	490.	22.9 65.6 -3.1	0.66	268.	B1 169.0 246.0 14486. -2 2	B1 434.0 451.0 0. -3 0	B4 454.0 469.0 0. -3 0				MRM
													SRM

Fig. 12-39 R3 - Summary Table

A/C			Time	X Y Z	Ma	psi	M1	M2	M3	M4	M5	M6	
BLAU1	FIGHTER	COCKPIT	490.	18.0 -82.2 -4.6	0.68	90.	R1 157.0 211.0 5060. -2 5	R3 164.0 218.0 5158. -2 5	R3 166.0 220.0 5316. -2 5	R3 316.0 353.0 19735. -2 5			MRM
							R2 423.0 432.0 3. -3 0						SRM
ROT 2	DESCORT	CGT	490.	24.7 65.6 -3.1	0.66	268.	B1 169.0 238.0 22875. -2 5	B2 260.0 309.0 26047. -2 5	B1 318.0 372.0 6248. -2 5	B4 372.0 405.0 2589. -2 5			MRM
							B1 423.0 432.0 596. -2 -3						SRM
ROT 3	DESCORT	CGT	490.	27.2 65.3 -3.1	0.66	268.	B4 178.0 252.0 24262. -2 5	B2 261.0 305.0 30882. -2 5	B4 314.0 349.0 15744. -2 5	B2 358.0 400.0 17815. -2 5			MRM
													SRM
ROT 4	BOMBER	CGT	490.	-14.1 65.7 -1.3	0.64	308.							MRM
													SRM

Fig. 12-40 R3 - Summary Table (cont.)

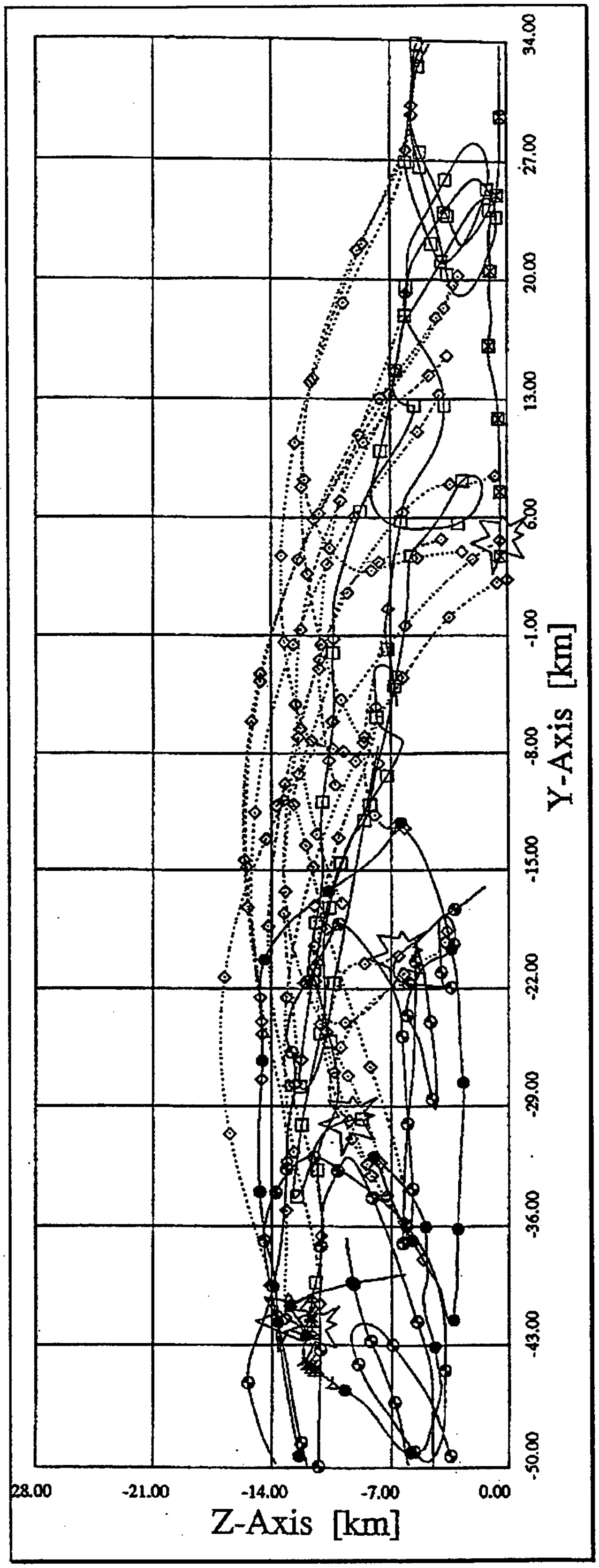


Fig. 12-41 R3 - Trajectory Plot (Z-Y Axis,"Blow Up")

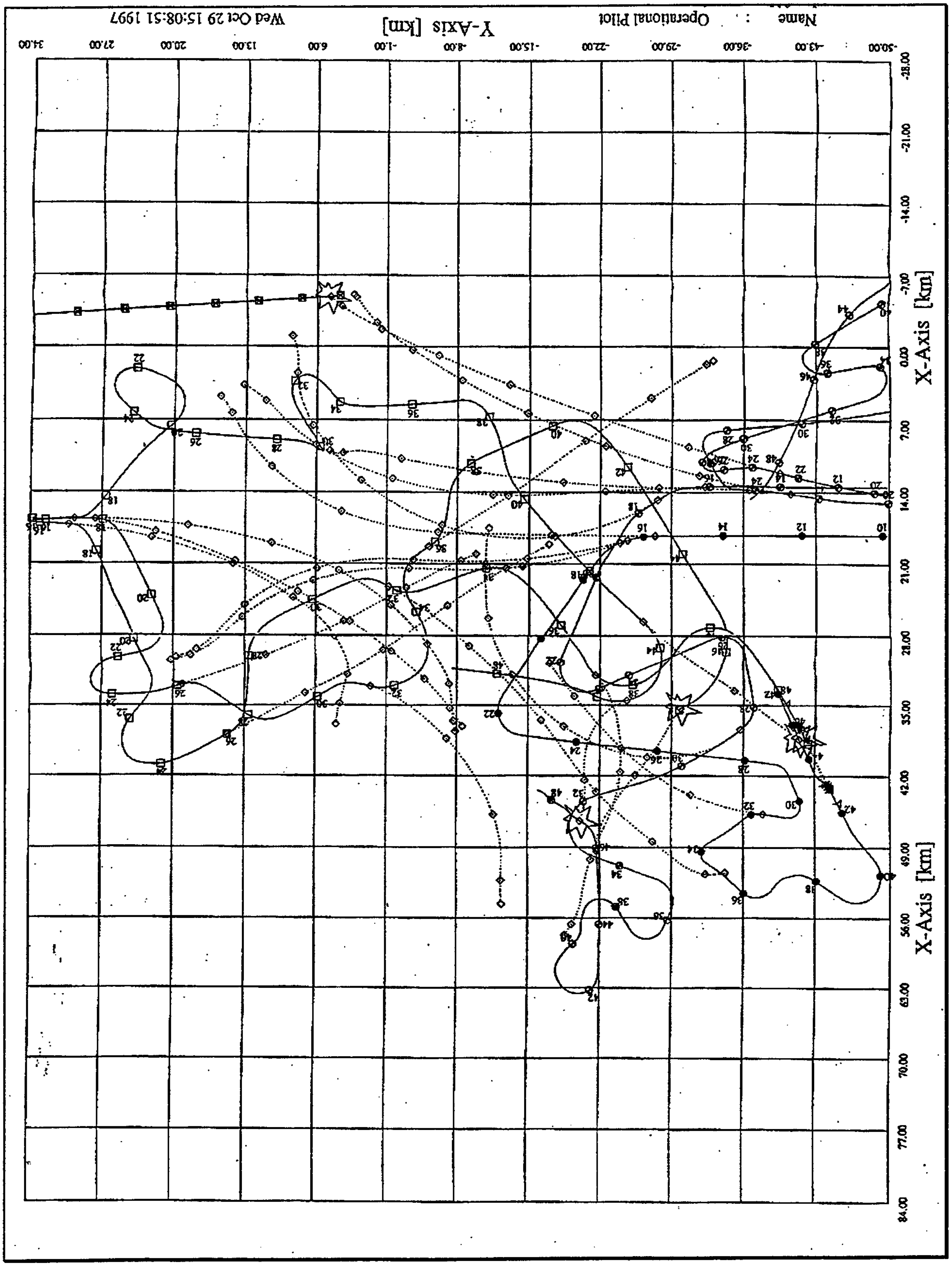


Fig. 12-42 R3 - Trajectory Plot (X-Y Axis,"Blow Up")

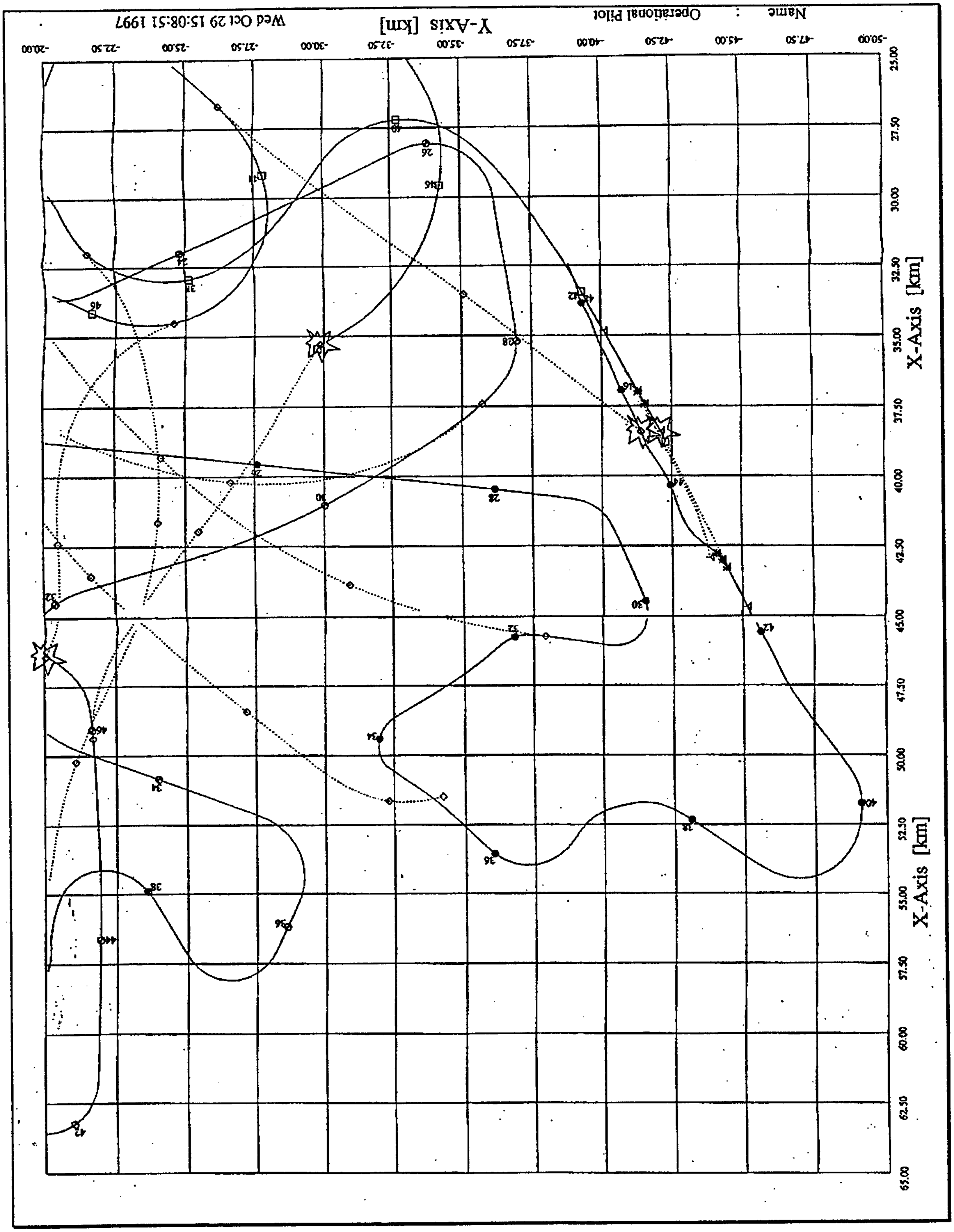


Fig. 12-43 R3 - Trajectory Plot (X-Y Axis,"Blow Up")

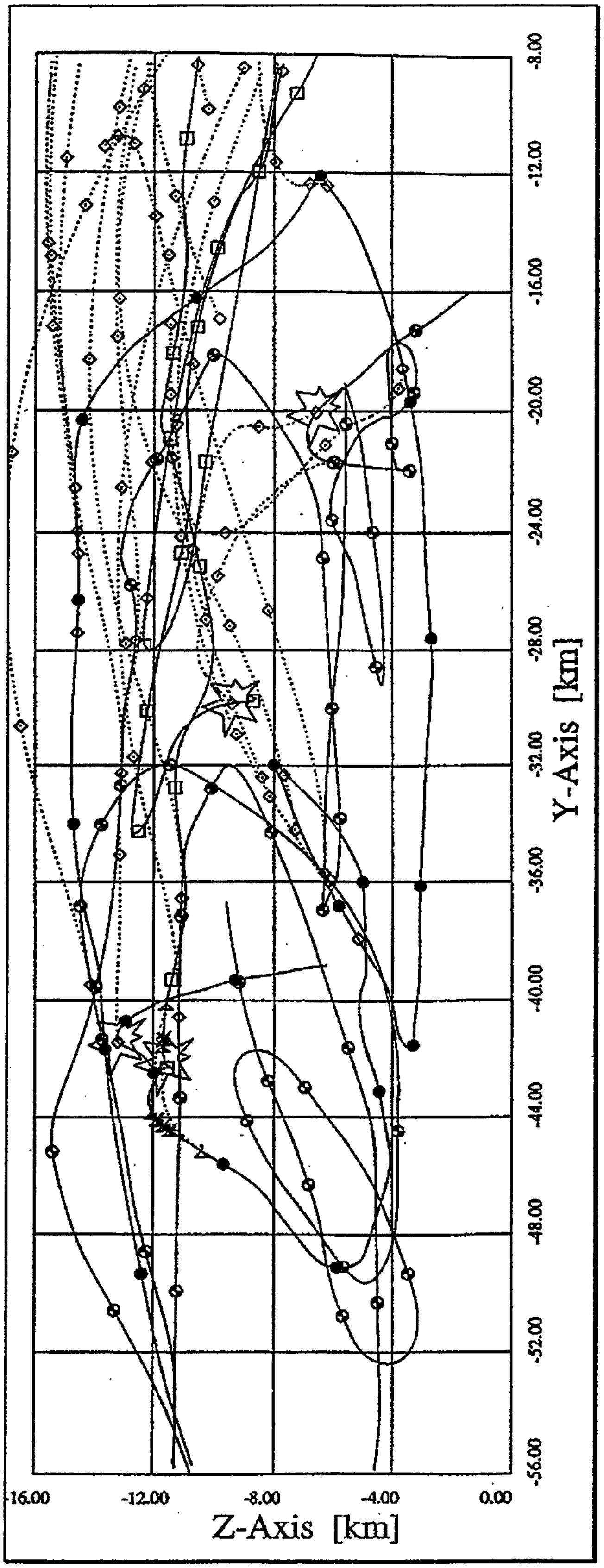


Fig. 12-44 R3 - Trajectory Plot (Z-Y Axis,"Blow Up")

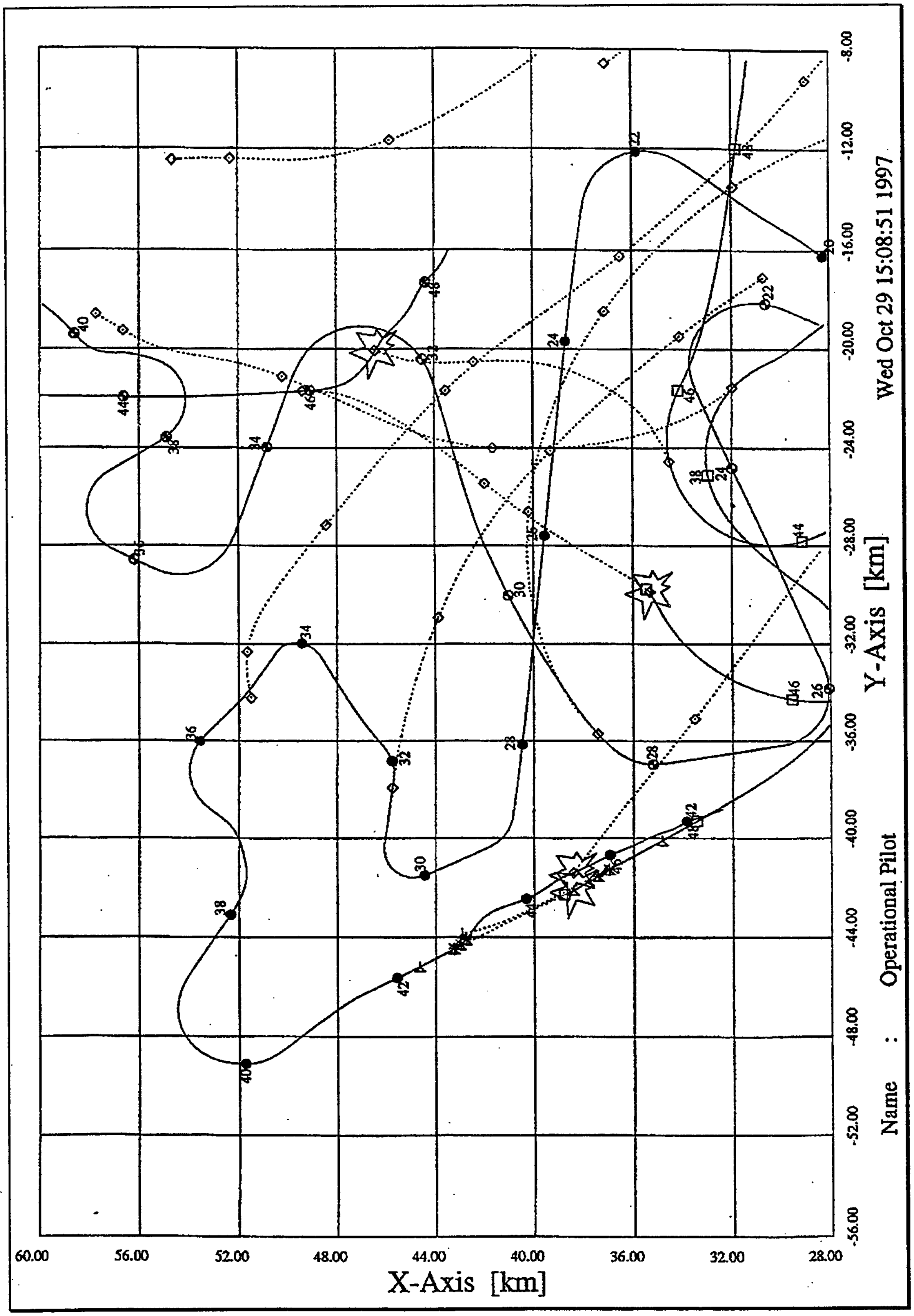


Fig. 12-45 R3 - Trajectory Plot (X-Y Axis,"Blow Up")

13. Appendix E Methods for Dasa-NIC-Interface Access [Dasa]

13.1 Methods for filling data in iEntity, iCommand, iData, iRadar, iJammer objects.

To fill an **iEntity object** with data the following methods are available:

```
void wtime_stamp (float64 time_stamp); // seconds of current hour
void wAbsTimeStamp( uint8 flag); // true = absolute time stamp
void wEntity_ID( EntityID &);
void wEntity_ID( uint16 site, uint16 application, uint16 entity);
void wEntity_Type( EntityType &);
void wEntity_Type( uint8 kind, uint8 domain, uint16 country,
                   uint8 cat, uint8 subcat, uint8 spec, uint8 extra);
void wEntity_Type( uint8 EntityTypeFormat, int32 entity_type);
void wDRAlgorithm( uint8 DRAlgorithm);
void wLocation( Position_3D &Location, int CoordinateSystemID, int UnitId);
void wOrientation( Orientation_Data &Orientation, int OrientationId);
void wLinear_Vel( Vector_3D & Linear_Vel, int CoordinateSystemID, int UnitId);
void wLinear_Acc( Vector_3D & Linear_Acc, int CoordinateSystemID, int UnitId);
void wAngular_Vel( Vector_3D & Angular_Vel);
void wAngular_Acc( Vector_3D & Angular_Acc);
void wEntityAppearance( uint32 EntityAppearance);
void wForce_ID( uint8 Force_ID);
void wRole( uint8 Role);
void wnShortRangeMissiles( uint8 numberShortRangeMissiles);
void wnMediumRangeMissiles( uint8 numberMediumRangeMissiles);
void wMissileNumber( uint8 MissileNumber);
void wPower( uint8 Power);
void wFuelFlow( uint16 FuelFlow);
```

```
void wMissileStatus( uint8 MissileStatus);
void wMissileBreakC( uint8 MissileBreakCondition);
void wEntityActive( uint8 flag);        // true = active
void wMannedCockpit( uint8 flag);  // true = manned
void wGearState( uint8 flag); // true = gear down
void wAfterburner( uint8 flag);        // true = afterburner on
void wLauncher( EntityID &Launcher);
void wTarget( EntityID &Target);
void wFlare( Flare_Data &);
void wChaff( Chaff_Data &);
```

<u>General methods available for an **iEntity** object:</u>

```
char* PrintData( char* text);  // prints contents of iEntity object
BOOLEAN Aircraft();           // returns TRUE if entity is an aircraft
BOOLEAN Missile();            // returns TRUE if entity is a missile
BOOLEAN AircraftMissile();  // returns TRUE if entity is an AC or missile
BOOLEAN Flare();              // returns TRUE if entity is a flare
BOOLEAN Chaff();              // returns TRUE if entity is a chaff
BOOLEAN FlareChaff();        // returns TRUE if entity is flare or chaff
```

===

NOTES:

'wLocation' writes ' Location ' into internal representation. The Coordinate System of ' Location ' is ' CoordinateSystemID ' and the Unit is 'UnitId'.

'wOrientation' writes ' Orientation ' into internal representation. The representation of ' Orientation ' is according to 'OrientationId'.

```
typedef enum
{
  FLAT_EARTH_NED,          // xNorth        yEast           zDown
  WGS_84,                  // WorldCoordinateSystem WGS 84
```

```
    FLAT_EARTH_NEU,        // xNorth      yEast        zUp
    FLAT_EARTH_ENU,        // xEast       yNorth zUp
    LATLONALT              // xLatitude,  yLongitude,  zAltitude
} CoordinateSystemID;


typedef enum
{
    METER,                 // METER/SEC , METER/SEC^2 respectively
    FEET                   // FEET/SEC , FEET/SEC^2 respectively
} UnitId;
typedef enum
{
    QUATERNIONS,           // P0=q0,      P1=q1,       P2=q2,       P3=q3
    EULER_ANGLES           // P0=psi,     P1=theta,    P2=phi
} OrientationID;


typedef enum
{
    Dasa,
    WL
} EntityTypeFormat;
typedef enum
{
    EFA_TYPE             =  1,
    F15E_TYPE            =  55,

    SAM_IHAWK_AFU        = 101,
    SAM_IHAWK_SQN_PIP2   = 102,
    SAM_IHAWK_SQN_PIP3   = 103,
```

```
    SAM_PATRIOT          = 105,
    SAM_TLVS             = 110,

    RADARSITE_TYPE       = 200,
    CRC_LOCAL            = 201,
    CRC_GRND_REMOTE      = 202,
    CRC_AIR_REMOTE       = 203,

    AAM_MISSILE_TYPE     = 1000,
    MR_MISSILE_TYPE      = 1001,
    SR_MISSILE_TYPE      = 1002,

    SAM_HAWK_M3_MISSILE_TYPE         = 1101,
    SAM_PATRIOT_PAC2_MISSILE_TYPE = 1102,
    SAM_PATRIOT_PAC3_MISSILE_TYPE = 1103,
    SAM_TLVS_MISSILE_TYPE            = 1120,

    FLARE_TYPE           = 2000,
    CHAFF_TYPE           = 3000,
    SIF_TYPE             = 4000,
    BOMB_TYPE            = 5000,
} DasaEntityTypes;
```

==

To fill an **iCommand object** with data the following methods are available:

```
void wSender_ID( EntityID & entity_id);
void wSender_ID( uint16 site, uint16 application, uint16 entity);
void wReceiver_ID( EntityID & entity_id);
```

```
void wReceiver_ID( uint16 site, uint16 application, uint16 entity);
void wCommand( uint8 Command);
void wEffectTime( float64 EffectTime);        // seconds of current hour
```

General methods available for **iCommand** object:

```
char* PrintData( char* text);  // prints contents of iCommand object
```

```
==============================================================

NOTES:

typedef enum
{
  Cmd_SM_INIT,                   // commands from Scenario Manager
  Cmd_SM_EXECUTE,
  Cmd_SM_FREEZE,
  Cmd_SM_TERMINATION,
  Cmd_SM_REINIT,
  Cmd_SM_RELEASE,
  Cmd_INIT,
  Cmd_RUN,
  Cmd_HOLD,
  Cmd_END,
  Cmd_SEND_INIT_DATA  = 20       // send your init data to controller
} CommandPduCommands;

==============================================================
```

To fill an **iData object** with data the following methods are available:

```
void wSender_ID( EntityID & entity_id);
void wSender_ID( uint16 site, uint16 application, uint16 entity);
void wReceiver_ID( EntityID & entity_id);
void wReceiver_ID( uint16 site, uint16 application, uint16 entity);
```

```
void wCommand( uint8 Command);

//~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
        // write <NumDataBytes> Data Bytes from <p_theData> adress
        // into iData object Data area
//~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
BOOLEAN wData( void *p_theData, uint16 NumDataBytes);
void   wDataType( uint32 dataType);
```

<u>General methods available for **iData** object:</u>

```
char* PrintData( char* text);  // prints contents of iData object
```

To fill an **iRadar object** with data the following methods are available:

```
void wSender_ID( EntityID & entity_id);
void wSender_ID( uint16 site, uint16 application, uint16 entity);
void wReceiver_ID( EntityID & entity_id);
void wReceiver_ID( uint16 site, uint16 application, uint16 entity);
uint16   RadarMode;
uint16   RadarType;
float32  frequency;          // MHz
float32  beamDirection;      // radian
float32  beamElevation;      // radian
float32  beamStrength;       // dB
```

<u>General methods available for **iRadar** object:</u>

```
char* PrintData( char* text);  // prints contents of iRadar object
```

==

NOTES:

```
typedef enum
```

```
{
  CW,
  PDOP,
  IHAWK_IPAR      =        11,
  IHAWK_ICWAR,
  IHAWK_IHIPIR,
  PATRIOT_RS,
  TLVS_RS
} DasaRadarTypes;


typedef enum
{
  SURVEILLANCE       = 1,
  TRACKING,
  TERMINAL_PHASE
} DasaRadarModes;
```

==

To fill an **iJammer object** with data the following methods are available:

```
void wSender_ID( EntityID & entity_id);
void wSender_ID( uint16 site, uint16 application, uint16 entity);
void wReceiver_ID( EntityID & entity_id);
void wReceiver_ID( uint16 site, uint16 application, uint16 entity);
uint16  JammerMode;
uint16  JammerType;
float32 frequency;          // MHz
float32 headingToJammer;    // radian
float32 elevationToJammer;  // radian
float32 signalStrength;     // dB
```

General methods available for **iJammer** object:

char* PrintData(char* text); // prints contents of iJammer object

13.2 Methods for retrieving data from iEntity, iCommand, iData, iRadar, iJammer objects.

To retrieve the data from an **iEntity object** the following methods are available:

float64	rtime_stamp () const;
uint8	rAbsTimeStamp() const;
const EntityID	&rEntity_ID() const;
uint16	rEntityNumber() const;
uint16	rApplicationNumber() const;
uint16	rSiteNumber() const;
const EntityType	&rEntity_Type() const;
int32	rEntity_Type(uint8 EntityTypeFormat) const;
uint8	rDRAlgorithm() const;
Position_3D	rLocation(int CoordinateSystemID, int UnitId) const;
Orientation_Data	rOrientation(int OrientationId) const;
uint8	rOrientatId() const;
Vector_3D	rLinear_Vel(int CoordinateSystemID, int UnitId) const;
Vector_3D	rLinear_Acc(int CoordinateSystemID, int UnitId) const;
Vector_3D	rAngular_Vel() const;
Vector_3D	rAngular_Acc() const;
uint32	rEntityAppearance() const;
uint8	rForce_ID() const;
uint8	rRole() const;
uint8	rnShortRangeMissiles() const;
uint8	rnMediumRangeMissiles() const;
uint8	rMissileNumber() const;

```
uint8            rPower() const;
uint16           rFuelFlow() const;
uint8            rMissileStatus() const;
uint8            rMissileBreakC() const;
uint8            rEntityActive() const;
uint8            rMannedCockpit() const;
uint8            rGearState() const;
uint8            rAfterburner() const;
const EntityID   &rLauncher() const;
const EntityID   &rTarget() const;
Flare_Data       rFlare() const;
Chaff_Data       rChaff() const;
```

==

NOTES:

' rLocation ' reads Entity Location and converts it according to

' CoordinateSystemID ' and ' UnitId '.

' rOrientation ' reads Entity Orientation and converts it according to

' OrientationID '.

==

To retrieve the data from an **iCommand object** the following methods are available:

```
const EntityID   &rSender_ID() const;
const EntityID   &rReceiver_ID() const;
uint8 rCommand() const;
float64 rEffectTime() const;
```

To retrieve the data from an **iData object** the following methods are available:

```
const EntityID   &rSender_ID() const;
```

```
const EntityID          &rReceiver_ID() const;
uint8 rCommand() const;
//~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~       // read <NumDataBytes> Data Bytes from iData object and
        // copy them into <p_theData> adress
//~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~   BOOLEAN rData( void *p_theData, uint16 NumDataBytes);
uint32 rDataType( void) const;
```

To retrieve the data from an **iRadar object** the following methods are available:

```
const EntityID          &rSender_ID() const;
const EntityID          &rReceiver_ID() const;
uint16  RadarMode;
uint16  RadarType;
float32 frequency;          // MHz
float32 beamDirection;      // radian
float32 beamElevation;      // radian
float32 beamStrength;       // dB
```

To retrieve the data from an **iJammer object** the following methods are available:

```
const EntityID          &rSender_ID() const;
const EntityID          &rReceiver_ID() const;
uint16  JammerMode;
uint16  JammerType;
float32 frequency;                // MHz
float32 headingToJammer;          // radian
float32 elevationToJammer;        // radian
```

```
float32  signalStrength;          // dB
```